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STREAM QUALITY PRESERVATION THROUGH PLANNED URBAN DEVELOPMENT

Robert E. Coughlin, et al

Regional Science Research Institute

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Stream Quality Preservation through Planned Urban Development

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STREAM QUALITY PRESERVATION THROUGH PLANNED URBAN DEVELOPMENT

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ABSTRACT

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This report was submitted in fulfillment of Grant No. 16110 DYX to the Regional Science Research Institute under the sponsorship of the Office of Research and Monitoring, Environmental Protection Agency.

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SUMMARY OF FINDINGS

Land use planning of urban development can have a significant effect in preventing deterioration of stream water quality and in preventing the enlargement of channels which typically accompanies urban development.

Effects of Urbanization on Stream Channel Enlargement

Development near the stream and on steep slopes is deleterious to the water resource system. The effects on streamflow and channel enlargement of development in these critical areas, however, are probably less important than the effects on erosion and sewage effluent.

Statistical analysis of a large sample of watersheds indicates that the most important consideration concerning streamflow and channel enlargement is type of development. For example, if a given amount of residential development is storm sewered, it will cause much greater channel enlargement than if storm sewers are not provided. The provision of storm sewerage appears to make much more difference than the location of the development relative to the stream. As another example, large contiguous areas with impervious surface may have a greater effect than smaller scattered sites with the same total amount of impervious surface.

The effect of a given amount of development on channel enlargement is greater for steeply sloped watersheds than for flatter ones. Two findings suggest that development should be kept to a minimum at headwaters areas. First, the location of development at upstream points will affect a larger length of channel than will development at downstream points. Second, the absolute amount of channel enlargement resulting from a given absolute amount of impervious surface decreases with increase in watershed area, which of course increases as one goes downstream.

Effects of Urbanization on Stream Water Quality at Low Flow

Urbanization has a pervasive effect on water quality. During low flow conditions significant effects involving urbanization have been found for a number of chemicals which are often considered as being geologically determined rather than produced primarily by human activities.

The pattern of effects associated with different types of urbanization tends to be similar for a wide variety of chemicals. Specifically, relatively large increases in chemical concentrations are associated with watershed population in unsewered dwelling units, and with population in dwelling units whose sewage is disposed of within the watershed. Smaller, but nevertheless significant, increases are associated with population in dwelling units whose sewage is sewered out of the basin. The latter results indicate that urbanization is likely to cause lower water quality regardless of what is done with sewage.

The study has indicated that the contribution of population in unsewered dwelling units to streamwater pollution is related inversely to the distance of such units from the stream channel. Other findings of the study are that chemical concentrations are systematically related to manufacturing employment and to soil drainage characteristics.

Effects of Urbanization on the Preservation of Open Space Use

A study conducted to determine the amount of development which typically occurs near streams with normal urbanization indicates that less development tends to occur near streams than occurs some distance away. The relative lack of development near the stream is related statistically to the size of the drainage area of the stream and the steepness of the stream valley. Thus, natural development forces appear to be consistent with the objectives of stream valley planning.

Although a rather high percentage of streamside land segments have no development at all, the amount of development in such segments rises as township population density rises. In fact, it would appear that in the early stages of development streamside sites are left undeveloped, perhaps because of steep slopes or wet soil conditions. Thus, in the later stages of development streamside sites are among the few sites still undeveloped, and unless they are purchased for public open space they are then likely to be developed more intensively than surrounding areas.

Evaluation of Effects of Urbanization: Aspects of Environmental Preference

A number of pilot studies indicate that untrained field observers can identify water quality reasonably well. However, no significant correlations were found between chemical measures and preference ratings for the stream, its surrounding area, or the area overall.

Although there is a general consistency between chemical measures of water quality, perceived attributes, and preferences for the stream and surrounding area, the field-observer study does not indicate that water pollution is a strong determinant of preference. Criteria other than water quality were evidently more important to the observers, who were generally agreed on the relative attractiveness of a stream.

Other investigations carried out indicate that one can expect to find a reasonably high level of agreement on the attractiveness of alternative environments. Generally preferred landscapes are those which are park-like, with mowed grass and scattered large trees rather than completely natural or wild. Specific natural features, however, are less important than an illusion of naturalness, and this can be most easily lost through the presence of negative characteristics such as junk, ugly development, or other man-made "misfits."

Evaluation of Effects of Planning: Fiscal Benefits

Properly planned urban development would result in higher ground water levels and in more constant streamflow than would be expected under typical urbanization. However, a planned pattern of land use is likely to have little effect on seasonal high and low flows. Therefore, it is doubtful that any substantial savings in capital or operating costs of reservoirs could be realized.

Somewhat higher water quality might be expected with properly planned urban development. Resulting savings in water purification costs, however, would be minimal. Higher water quality must be justified primarily on aesthetic and recreational grounds.

A good land use plan would result in the avoidance of flood losses in two ways: through reduction in the increase of peak flows associated with urbanization, and through prevention of development in areas subject to flooding. The latter of these is probably the more important.

Fiscal benefits to the taxpayer do not appear to be the major consideration in evaluation of land use plans. Non-fiscal benefits, which accrue directly to individuals (such as environmental benefits) would appear to be more important.

Evaluation of Effects of Planning: Non-Fiscal Benefits

Actual use and perceived suitability for use of a stream, and perceived land values near the stream, are greater if the stream water is cleaner, and greater for nearby residents than for those living at greater distances. The effects of changes in water quality and distance to residence on the above variables can be determined from regression equations and curves presented in the report.

Capitalization of Effects of Environmental Preservation in Land Values

Nearly all of the effects of stream valley preservation, and especially the non-fiscal or environmental benefits, can be expected to be registered in higher land values. This increase in value is enjoyed directly by land owners, who themselves constitute a significant proportion of the public, and secondly by the general public through higher property tax revenues.

Analysis of property values around a large stream valley park in Philadelphia indicates the existence of a land value gradient, with higher values close to the park. The land value effect of the park falls from $15,000 per acre at 100 feet to $1,700 per acre at 2,500 feet (this being an area for which the "base" land value is roughly $25,000 per acre).

Conclusions

The results of the study indicate that open space effects of land use planning may exceed the stream quality effects in generating public benefits. The value which persons derive from stream valley areas seems to be related more strongly to the existence of open space per se than to the condition of the stream itself. In addition, the major fiscal gains associated with preserving stream quality appear to be minor relative to the amenity value of open space.

RECOMMENDATIONS

A land use plan which would restrict urban development near the stream and on steep slopes would have beneficial effects on stream hydrology and water quality, and would provide a desirable environment with substantially more open space than would be achieved through normal development.

Such plans should be developed for a number of watersheds and implemented as demonstration and research projects. Only through studying actual examples can we gain a well-grounded knowledge of expected environmental benefits and the evaluation of them which would be made by residents and visitors. Actual demonstration projects would provide experience on residents' acceptance of such plans and on the actual effect on land values of the attractive and guaranteed environment which such plans promise.

In such plans, development should be restricted near streams and on steep slopes. Large contiguous paved areas should be avoided. Also, where a choice exists among small watersheds, development should be restricted in areas containing the headwaters of streams.

If significant impervious areas are unavoidable, allowance for artificial detention and dispersal of storm water should be provided to the extent possible. This is in contrast to most urban storm drainage engineering which speeds water to the stream.

The natural association between the preservation of open space and the preservation of stream quality should form a basis for the development of environmental preservation plans. The choice of land to be preserved should represent some mix of the two strategies of maximizing open space value to residents and minimizing stream quality deterioration.

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I. INTRODUCTION

Planning and Management of Stream Systems

For many decades one of the major emphases in environmental planning and management has been the management of stream and river systems. This effort has resulted in a tradition of highly developed techniques for planning and plan evaluation, which have been effective in identifying and remedying a number of hydrologic and water quality problems. These analyses have concentrated on the stream itself and have resulted in many well worked-out systems of flood control, flow regulation, water purification, and channel widening and straightening.

It has long been recognized that a stream is part of a larger system which consists of its entire watershed, including geological and vegetative characteristics and man-made structures. Programs of action to treat the entire system have been most successful for rural areas. The effects of rural land uses such as agriculture and forestry have been studied extensively and are now quite well understood. In addition, these uses have not simply been accepted as a given. It has been considered appropriate public policy to vary rural land uses and their location in order to achieve environmental objectives.

In urban areas, in contrast, the effects of different types and amounts of development are not well understood, and only the stream itself is considered an appropriate object of management. Streams are dammed, widened, deepened, lined, culverted, and paralleled by levees, but little consideration is given to changing amounts and types of land use within the watershed in order to reduce the deleterious effects of urbanization. There are no urban counterparts of the Soil Conservation Service's policies of reforestation, strip cropping, and contour plowing, which have become accepted practices in many rural watersheds. As a result of this inattention to the entire system, water resource planning in urban water-

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sheds has led to corrective rather than preventive measures.

The lack of attention given to urban development in the past is understandable, since cities covered a very small portion of any large watershed. They tended to grow in a very compact pattern, determined by technological necessities such as the suitable locations for railroad lines and gravity flow sewers. As a result, the range of possible choice over the pattern of development was relatively small.

More recently, the technological constraints have been released, making development possible almost anywhere. As a result it is now more possible to guide urban development into patterns which would be least harmful to water resources. Population growth rates of urban concentrations has been covering much more land per person. Since much more land is now involved in urbanization, it is also now more necessary to plan for the effects of urban development or water resource systems.

A Planning Approach for the Preservation of Water Resources

Consideration of an urbanizing watershed as a total system suggests that many of the deleterious effects may be minimized so that fewer remedial measures are necessary. Such an approach would consider certain aspects of urban development in addition to the usual factors considered in water resource system planning. First, the total amount of urbanization in a watershed might be limited in order to keep stream quality within an acceptable range. Second, the location of development within a watershed, which may be an important determinant of the effect of urbanization on a stream, might also be controlled. For example, severe restriction of development close to streams might limit the deleterious effects of stream water quality. Third, the type and design of development might be specified in order to avoid unnecessary harmful effects. For example, the construction of very large areas of impervious surface such as shopping centers, which may have particularly strong effects on the peak flows of small streams, should perhaps be restricted.

The object of guiding the development of urbanized regions in this way would be: to maintain water quality; to prevent the increase in frequency of flooding and the increase of peak flows associated with moderate to heavy rainstorms; to prevent enlargement and degradation of the channel which accompanies increases in flooding; to prevent reduction of the "base flow" of the stream during periods of little rainfall; and to avoid losses due to flooding of development on flood plains.

The above objectives are related to the economic value of the stream, as, for example, the obvious importance of water quality to its suitability for domestic use. The effects are also related to the amenity value of the stream, that is, its value as an aesthetic and recreational resource. This relationship, and the fact that the planning system described involves the allocation of land uses, suggests that water resource planning can build upon people's evident natural attraction to watercourses. The preservation of open space near the stream, therefore, should also be an objective.

This natural link between planning for water resource preservation and planning to preserve open space and natural amenity suggests that the concepts of water quality and the stream flow regimen should be enlarged to include the setting of the stream as well as the water itself.

The Plan for the Upper East Branch of the Brandywine

This broader approach to water resource planning has been followed in but few plans. One of the most complete is the Plan and Program for the Brandywine [Institute for Environmental Studies, RSRI and USGS, 1968], which was prepared for the 37-square-mile watershed of the upper east branch of the Brandywine Creek in Chester County, Pennsylvania. This plan specified various restrictions on development with respect to natural features, and specified legal and administrative measures for enacting the restrictions. The plan was developed following study of attitudes, land values, and population growth, as well as the physical characteristics of the watershed and the existing legal and administrative power of government. Similar studies were carried out for the nearby Pickering Creek watershed with a view to comparing the future (i.e., after urbanization has taken place) water quality and hydrologic effects in the Brandywine watershed with effects in a watershed with typical planning and legal controls.

The development of the Brandywine Plan was based on the delineation of areas where development would be critical to the water resource system. These areas consisted of flood plains, the area within 300 feet of all streams and swales, areas of over 15% slope, and wooded areas of 10 or more contiguous acres. These critical areas constituted the Water Resources Protection District. Within this District, the following restrictions were placed on development:

On flood plains - No new development or additions to existing structures would be permitted.

On other areas within 300 feet of all streams and swales (known as the stream buffer area) - No new development except for additions to existing uses would be permitted. However, development would be restricted to 2,000 square feet per parcel, or 5% of the parcel area, whichever is greater. In addition, extensive impervious areas such as parking lots would be prohibited

Woods and slopes- No new structure could be built on a lot of less than four acres. Also, total impervious area would be limited to 2,000 square feet per parcel or to 5% of parcel size, whichever is greater.

For areas outside the Water Resources Protection District, where most urbanization would occur, "a system of works--water supply, erosion control, surface runoff, and waste disposal--is proposed to reduce markedly the usual harmful effects" [Institute for Environmental Studies, et al., 1968, p. III-B-9].

The primary method proposed for establishing the restriction was the purchase of conservation easements by the Chester County Water Authority. In turn for granting an easement, each landowner would be paid an amount equal to the loss in value of his land resulting from the restrictions imposed. This amount would vary depending upon the amount of his land in each of the categories of the Water Resources Protection District, and the potential development value of his land. Following the purchase of easements the landowner would retain all prior rights in the land except those specified in the easement. For example, no one except the landowner would have the right of access onto the land.

The Brandywine Plan was debated thoroughly in the community over a period of two years, but because of local opposition, was never carried out. Among the many reasons for this opposition were: the development restrictions and legal instruments proposed were unfamiliar, relatively complex, and therefore difficult to understand; the effects of the easements on the future value of land could not be determined with a sufficient degree of accuracy, especially because there is virtually no market experience with such easements to be referred to; the imminence and inevitability of urban development was not apparent to the residents of the watershed; and distrust of government, based partly on recent power line and dam projects, was endemic [Keene and Strong, 1970].

Agreement with the objectives of the plan, however, was generally asserted by local leaders who established a regional planning commission to achieve the objectives of the plan, but with methods acceptable to the residents of the watershed and with operations fully under local control. The regional planning commission has been meeting since January 1968, but to date has not announced a plan of action.

Research on the Physical Effects of Planned Urban Development and on their Evaluation

The Brandywine Plan received considerable attention throughout the country. The physical solutions to environmental problems proposed in the Plan were based on inadequate scientific knowledge, however. It was not possible to estimate with any precision the amount of improvement in stream quality which would result from the Plan, relative to what conditions would otherwise be. In addition, it was not possible to form an estimate of the value which would actually be derived from these physical effects by the present and future residents of the area.

When the Brandywine Plan was developed, very little was known about the precise effects of amount, type, and spatial patterns of urbanization on stream hydrology and water quality. For example, although it was known that increases in the amount of land area rendered impervious in a watershed tend to increase peak flows, there was little information available concerning the relative effects of different types of impervious area and the importance of where the impervious area was located with respect to the stream, steeply sloping land, and other natural features. The same sort of information was lacking with regard to water quality; little was known about typical effects produced by leakage from sewer pipes, contamination from septic fields, and other ways in which urbanization might be expected to affect stream water quality, even if collection and treatment of sewage were practised. In specific cases, or under various assumptions, engineering-type formulas might be applied to predict these effects. But, little was actually known about the typical magnitude of impacts of urbanization on stream flow and water quality.

In the Brandywine Plan, the land use restrictions proposed were based upon the best professional judgment available [Leopold, 1970; Rogers and Associates, 1968]. With regard to the single most important provision of the Plan, namely the preservation of a 300-foot strip in natural uses along all streams and swales, it was reasoned that keeping development back from the stream would minimize both water quality and streamflow effects due to the ability of the intervening land to absorb excess runoff, and to purify ground water moving towards the stream. However, there was little information available to indicate what would be the "proper" width of the buffer area around the stream.

In preparing the Plan, it was also difficult to estimate the value to the public of the physical effects of the Plan. As with any plan, it is important to be able to demonstrate that the value which the public places on the effects of the plan outweigh the various costs incurred in carrying out the plan. Some of these value elements could be expressed fairly readily in dollar terms such as the value of reduced flood damages and reduced water treatment costs, but others are much more difficult to quantify. The latter value components include the aesthetic enjoyment of preserved stream valleys and the use people would make of them.

The research summarized in this report was designed to gain information regarding the questions raised by the Brandywine Plan, which would be useful in the formulation and evaluation of future plans.

Table 1 below provides an outline of the elements involved in evaluation of a plan similar to the Brandywine Plan. The rows of the table identify the three major physical effects which would result from the plan: namely, more open space, better water quality, and more stable streamflow than would result in the absence of the plan. The columns denote the value components which would be affected by the physical changes. These include: more active use and visual enjoyment of the stream and streamside areas; various ecological benefits such as more diversified fauna; and reduced costs resulting from flood damages and water treatment. The "X's" in the table denote probable relationships between physical changes and value components.

Table 1

CONCEPTUAL SCHEME FOR EVALUATION OF EFFECTS OF A PLAN FOR STREAM VALLEY PRESERVATION

Physical Changes	More Active Use	More Visual Enjoyment	More Ecological Benefit	Reduced Flood Damages	Reduced Need for Water Treatment
More stable streamflow			X	X	
Better water quality	X	X	X		X
More open space	X	X	X	X	

The research summarized in this report involves eleven separate studies on the physical effects, the value-related effects, and the relationships between the physical effects and the value-related effects. Three studies, reported in Chapters II, III, and IV, are concerned with investigating each of the three major physical effects. Of necessity, the studies have been of the effects which occur with typical urbanization. Urban patterns such as that called for in the Brandywine Plan do not exist and therefore cannot be studied directly. The channel enlargement study (Chapter II) has been concerned with the effects of urbanization on stream channel enlargement, and by implication, on increased peak flows; the water quality study (Chapter III) has involved an investigation of relationships between various aspects of urbanization and a number of water quality indicators; and the open space study (Chapter IV) was designed to see how much development tends to occur in stream valleys in the absence of strong planning measures, such as conservation easements.

The other studies have been concerned with the first two value-related effects listed in the Table, namely active use and aesthetic enjoyment of the stream and its surrounding area. One study (reported in Chapter VI) deals with the general topic of active use of stream sites by nearby residents; in this study, the effect on use of distance of residence from the stream is investigated for each of a number of different uses, and the importance of various socio-economic factors is also examined. Another study (also in Chapter VI) has been concerned specifically with the relationship between use levels and stream water quality.

Several studies have been concerned with the general subject of visual enjoyment and aesthetic preference. These studies have dealt with basic questions, such as whether there is substantial agreement among individuals with regard to preference (in Chapter V), what factors are important to preference (in Chapter V), and whether persons' actions are consistent with their stated preferences (in Chapter VI). An additional study has been concerned with the relationship between aesthetic preferences for stream sites and water quality (in Chapter V).

An important aspect of all these value-related components is that they may be registered in terms of land values. That is, land values will be bid up in the vicinity of preserved areas. Two of the studies mentioned above provide background information with regard to land value effects, namely that dealing with residential preference (in Chapter VI) and that dealing with the effect of distance on use. Two additional studies have been carried out. The first relates land prices to characteristics and accessibility of parcels in the Brandywine area itself. The second provides an estimate of the land value gradient surrounding a major urban park in the City of Philadelphia (Chapter VII).

These studies have not succeeded in answering all the questions raised by the Brandywine Plan. However, many answers have been gained, and important conclusions can be reached regarding the true value of such a plan.

II. HYDROLOGIC EFFECTS

INTRODUCTION

The hydrologic effects of urbanization have been indicated in the introductory chapter. These are:

1) increase in peak flow magnitudes and frequency of flooding due to rendering of land impervious and altering of the drainage systems,
2) possible reduction of base flow of the stream in periods of low rainfall due to decreased infiltration to ground water storage, and
3) enlargement and degradation of stream channels due to changes in the stream flow regimen identified in (1) above.

In order to understand the interrelationships among these effects, it is necessary to describe briefly the nature of stream channels and "flood plains," and their relationship to the flow regimen of the stream.

The typical stream valley in rolling terrain has the following features: valley sides, a "valley flat" near the stream, and the stream channel itself. The location of the stream channel on the valley flat is usually not permanent; the channel typically migrates back and forth over long periods of time, and may in fact have occupied most or all of the valley flat at one time or another in its history. The movement of the stream, and the maintenance of the form of the channel, are described by the familiar "meander model" of stream behavior. Stream meanders are accepted as a general phenomenon, although the degree of sinuosity obviously varies tremendously among streams. The significant feature of meandering is the tendency for the stream channel to move laterally, in a direction outward from the direction of curvature. The stream bank at the outside of each bend tends to recede, due to erosion by the flow of the stream and other factors, and the inner bank tends to advance due to deposition of material by the stream. Thus the form of the channel remains generally the same while the channel moves laterally.

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The important point for our purposes is the nature and origin of the equilibrium channel form which is maintained during lateral motion. Various observers have noted that stream channels tend to be maintained at a size which is in accordance with the higher flows of the stream (e.g., the flows following major storm events). Specifically, the stream channel tends to be maintained at a size such that one or both banks are overflowed only about every 1.5 years on the average. The existence of this common "bankful frequency" of streams has been documented by Leopold [1964, pp. 317-328], and seems to apply to a wide variety of stream sizes and conditions. Thus, according to the common-bankful-frequency hypothesis, the situation may be described as that in which the stream, moving laterally and maintaining a more or less constant width, builds up the bank on the side away from the direction of motion to just that height at which it is overflowed only every 1.5 years on the average, given the flow regimen of the stream; or equivalently, the bank is built to a height such that it "defines" a channel whose size is sufficient to contain all flows occuring with a recurrence interval less than 1.5 years.

The succession of these bank segments built over a period of time would, if the channel-bottom elevation remained constant, come to constitute a level plain, which is flooded every 1.5 years on the average. This is the "flood plain" of the stream. The flood plain may constitute a large portion of the valley flat; and portions of the flood plain may lie on both sides of the stream at some time (e.g., if the lateral motion of the stream has recently changed direction). But on the other hand, there may exist a valley flat without any true "flood plain" area at all.

The relevance of these considerations to the phenomenon of urbanization is that, given the change in streamflow regimen brought about by urbanization, the state of equilibrium between streamflow and stream channel is upset. With the existing channel size, a greater frequency of overbank flows will occur. Leopold [1968, pp. 7-11] has calculated that a 50% increase in the average annual flood of a small basin (i.e., the flow with a recurrence interval of 2.33 years), which might be associated with conversion of the basin from rural to 20% impervious and 20% "sewered," would result in a doubling of the number of overbank flows.

The response of the stream to increases in the magnitude of peak flows is a gradual process of channel enlargement. This process has been noted by many investigators, although it does not appear to have been studied systematically. Leopold has hypothesized that enlargement proceeds until the frequency of bankful flow returns to 1.5 years. That is, the channel enlarges until a state of equilibrium with the new streamflow regimen is reached, this equilibrium being the same in nature as that which prevailed before urbanization.

The process of enlargement typically involves a major deterioration in the aesthetic and recreational value of the stream. During the period of disequilibrium, the stream tends to have unstable, scoured, and unvegetated banks, and nearby valley surfaces are likely to be marked by freshly scoured flood channels and large areas of deposition. These characteristics greatly reduce the amenity value of the stream. The period of disequilibrium is likely to persist for a long time, due to the fact that the intensity of urban development tends to increase continually. And even if a stable situation is reached, the stream will be less attractive than originally, since it will still exhibit the negative characteristics generally associated with streams having widely variable flows.

The effect of urbanization on stream channel characteristics does not appear to have been studied in detail, but its effect on streamflow characteristics has been studied by a number of investigators. This research was summarized recently by Leopold [1968, pp. 4-6] in a publication dealing with the various hydrologic effects of urbanization.

Leopold assembled the results from six field studies, involving from one to eighty-one sample watersheds, and one study in which flows were simulated by a mathematical model. The data yielded by these studies, which were basically similar, were converted to a common form. This form was the ratio of stream discharge after urbanization to discharge before urbanization for a one-square-mile basin, where "discharge" referred to the mean annual flood (the peak flow having a recurrence interval of 2.33 years). Only two measures of watershed urbanization were considered: "percentage of area made impervious," and "percentage of area served by storm sewerage." Most of the studies dealt with little more information concerning urbanization than this, although several provided more complete descriptions of the nature of the drainage system [Anderson, 1968; Carter, 1961].

The data from these studies were summarized in the graph shown below as Figure 1, in which the percentage of area sewered was plotted against percentage of area impervious, with iso- lines used to show the ratio of peak discharge under urbanized conditions to the peak flow under unurbanized conditions.

According to the information summarized here, the ratio of post-urbanization discharge to pre-urbanization discharge would approach 7.0 for a totally sewered, totally impervious watershed. The ratio for a 50% impervious, 50% sewered watershed would be 2.8 or 2.9. The iso- lines tend to make a somewhat greater angle with the horizontal axis than with the vertical axis, indicating that area impervious is somewhat more important than area sewered, in percentage terms. This graph represents roughly the state of knowledge concerning the effect of urbanization on peak flow, as of 1968.

With only this amount of information, planning proposals could be justified only insofar as they involved limiting the total amount of development or the proportion of development sewered. It would obviously be desirable to have information concerning different types of development, and particularly the effects associated with development at different locations within the watershed. Location would be relevant both insofar as it involves location with respect to natural features, such as land slope and soil type, and also as it determined distance and path of flow from developed areas to downstream points. For example, it might turn out that merely by guiding the location of development much of the effect on streamflow regimen and channel enlargement could be avoided.

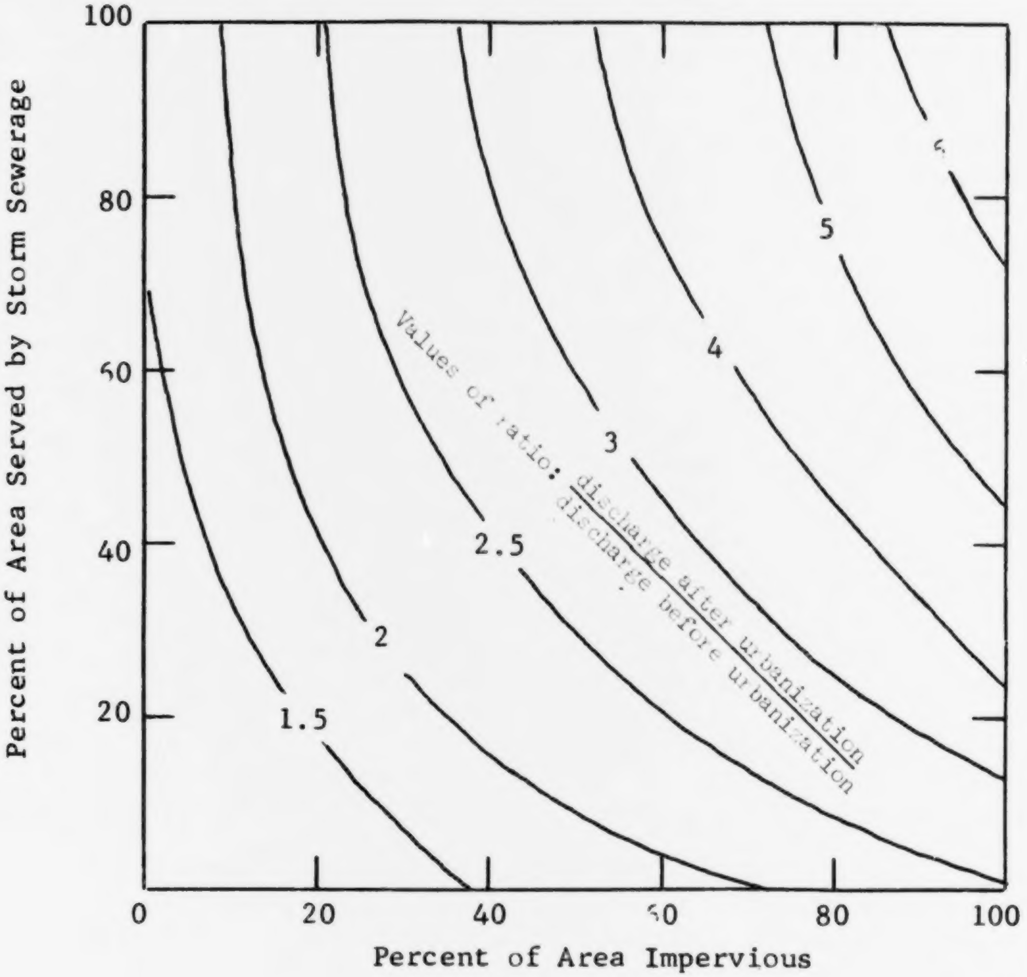


Figure 1

EFFECT OF URBANIZATION ON MEAN ANNUAL FLOOD FOR A 1-SQUARE-MILE DRAINAGE AREA

Source: Leopold, "Hydrology for Urban Land Planning," U.S. Geological Survey Circular 554, Washingtion, 1968; p. 5.

RESEARCH PROCEDURE

The research carried out under this grant has included an extensive study of the effect of urbanization on stream channel enlargement [Hammer, 1971]. The study is also relevant to streamflow due to the relationship between stream channel and streamflow characteristics discussed above. The channel measurement program was designed explicitly to maximize the association between stream channel size, measured as channel cross-section area, and characteristics of its streamflow regimen. Measurement criteria are discussed in detail elsewhere [Hammer, 1970]. These criteria made it possible to identify points at which one bank was judged to be a true flood plain, so that the channel was in "equilibrium" with flow. The use of channel measurements as surrogates for flow measurements enabled us to utilize a broad sample of watersheds without the high expense of a streamflow gauging program. The large sample has enabled us to examine a large number of factors simultaneously.

The study involved a sample of 78 small watersheds in the 5-county region comprising the piedmont portion of the Philadelphia metropolitan area. The basins range from 1 to 6 square miles in area, and vary in watershed condition from natural to highly urbanized. Twenty-eight of the watersheds contain only rural land uses; the remainder show some degree of urban development, with 16 more than 25% impervious.

A set of channel measurements was made pertaining to the stream reach at the mouth of each watershed. Each such measurement consisted of a channel cross-sectional profile, from which the width, depth, and cross-sectional area of the channel were computed.

A wide variety of land-use and other information was obtained for the sample watersheds. Each watershed was subdivided into 40-acre grid squares, and the amounts of land in the various uses were recorded for each grid square; similarly, topographic and drainage system information was recorded for each square. More than a dozen land-use categories were employed, including three types of impervious area: streets, houses, and "other" (primarily large structures and parking lots). For each type of impervious area, three different age categories were employed, so that account could be taken of the fact that channel enlargement takes place gradually. Other variables recorded for each grid square were: the length (and density) of sewered and unsewered streets; average soil drainage score; average land slope; distance and slope of flow-to-channel from the grid square; distance of flow in pipe; and a complete profile of the channel flow intervening between the grid square and the measurement point.

The availability of data for small sub-areas of each watershed made it possible to formulate and test a wide variety of "interaction" variables, in which the amount of land in some use would be weighted by another factor (e.g., land slope or street sewerage) and then summed over all grid squares to form a single observation for each stream. Thus, full utilization of the information available required the use of rather complex variables.

The analysis of these data has been based on the implicit assumption that the comparison of different watersheds exhibiting varying degrees of urbanization can indicate what happens to a single watershed over time as urbanization proceeds. This implicit assumption has, of course, been shared by other studies such as those summarized in Figure 1. The making of such an assumption (which is common in many fields of research) has received support from the very high level of statistical explanation obtained in this study, which can only be interpreted as meaning that, given topographic and other factors, urbanization affects different watersheds in a similar fashion. Hence, one can extrapolate from the comparison of different watersheds in different stages of urbanization to speak of the before-and-after effects of urbanization on a given watershed.

Channel cross-section area was related, using multiple regression analysis, to variables describing land uses and other watershed characteristics. The dependent variable in these regressions was the "channel enlargement ratio" which consisted of the ratio of observed channel area to the channel area which would be expected under natural conditions for a watershed of the given size. Natural channel area as a function of watershed size was estimated using the 28 rural watersheds in the sample. Over 100 different independent variables were tested, including a large number of interaction variables involving both land uses and natural features.

The analysis was conducted in two phases, each of which involved somewhat different forms of certain variables. For each phase of analysis, two different sets of final results were obtained corresponding to the inclusion and non-inclusion of variables in which "pre-war" residential development is considered separately. Thus, there are four sets of "final results." The variables appearing in these results are listed below. A full explanation of these variables and other matters is given in Hammer [1971]. For all the variables except the watershed shape index, the observation for a given stream consists of quantities measured for individual grid squares which have been summed over the whole watershed, in weighted or unweighted form. For variables involving land uses, the above-mentioned sum is divided by watershed area, so that the variable is in the form of a proportion of watershed area devoted to a given use.

The final variables, which emerged through a process of repeated testing in regression analysis, are listed below:

Dependent Variable

Y channel enlargement ratio. This equals the ratio of observed cross-section area of channel in square feet to the "natural" channel area. The latter was estimated to be $24.8\ A^{.657}$, where A is watershed area in square miles.

Independent Variables

X_1 land in forest

X_2 land in cultivation

X_3 land in golf courses

X_4 average soil drainage score (observed for individual grid squares and averaged over whole watershed)

X_5 watershed shape index "moment ratio." This variable measures the elongation, or deviation from circularity, of the watershed as a whole.

X_6 area of sewered streets, roads, and sidewalks which are more than four years old.

X_7 area of houses fronting on sewered streets. This variable consists of area of houses, driveways, outbuildings, and other impervious domestic area such as patios, for houses more than four years old which front on sewered streets. (Does not include houses with direct gutter connection to storm sewer.)

X_8 other impervious area (second phase). This variable includes all impervious area other than streets, houses and driveways, etc., plus area of houses with direct gutter linkage to storm sewers. (Applies to area greater than four years old; in regression number 4, area greater than 15 years old and area 4-15 years old are weighted differently.)

X_9 area of post-war sewered streets and sidewalks. Consists of area greater than four years old, with area 4-15 years old weighted less than area greater than 15 years old.

X_{10} area of pre-war sewered streets and sidewalks. Consists of area of streets constructed before World War II.

X_{11} area of post-war houses, driveways, etc., fronting on sewered streets. Similar to X_7 with houses built before World War II excluded, and with area 4-15 years old weighted less than area greater than 15 years old.

X_{12} non-impervious and unsewered residential area (used in second phase only). Consists of unsewered street and house area, plus tended land such as lawns in settled areas. (In regression 4, includes pre-war houses fronting on sewered streets.)

X_{13} residential impervious area weighted by proportion of streets sewered (used in First Phase). Includes area of houses, driveways, etc., plus area of streets assigned to "residential" category times the proportion of street length (i.e., in the grid square of observation) which consists of sewered streets. Applies to areas over four years old; does not include homes with direct gutter linkage to storm sewers.

X_{14} residential impervious area weighted by average land slope. Includes area of houses, driveways, etc., plus area of "residential" streets, times average land slope in the grid square of observation. Applies to areas over four years old; does not include houses with direct gutter linkage to storm sewer.

X_{15} pre-war residential impervious area. Similar to X_{13} but includes only streets, houses, driveways, etc., constructed before World War II.

X_{16} other impervious area (first phase). Consists of all impervious area other than streets, sidewalks, houses driveways, etc., plus area of "non-residential" streets and area of houses with direct gutter linkage to storm sewers. Applies to areas over four years old.

X_{17} slope-of-flow interaction variable (second phase). Consists of an impervious area index "I" weighted by the average slope of the flow path from the grid square of observation to the channel measurement point. (In regression 3, $I = 3.25X_6 + 0.83X_7 + 3.79X_8$; in regression 4, $I = 2.74X_9 + 1.95X_{10} + 2.04X_{11}, + 4.48X_8$.)

X_{18} watershed-size interaction variable (first phase). Consists of an impervious area index "I" weighted by watershed area to the exponent -1/2. (In regression 1, $I = 2.02X_{13} + 0.18X_{14} + 4.71X_{16}$; in regression 2, $I = 3.15X_{13} + 0.14X_{14} - 1.59X_{15} + 5.00X_{16}$.)

X_{19} flow-to-channel interaction variable (first phase). Consists of an impervious area index (as in X_{18}) weighted by the distance of flow--excluding flow in pipe--from the grid square of observation to the stream channel, divided by the square of the average slope of the flow path to the channel.

X_{20} flow-in-channel interaction variable (first phase). Consists of an impervious area index (as in X_{18}) weighted by a function of the lengths and slopes of channel intervals over which flow from the grid square must pass, this function being a positive function of distance and a negative function of slope. The function does not consider intervals of piped channel.

The primary difference between the first and second phases of analysis was that impervious area involving streets and houses was tested differently. In the first phase of analysis, the area of streets and sidewalks in each grid square was apportioned into "residential" and "non-residential" categories, according to the area of houses (and other impervious area) in the grid square. The "residential" street area was then added to the area of houses to form a single "residential impervious area" variable. Area of "non-residential streets" was added in with "other impervious area." This was done to minimize the problem of intercorrelation between variables. In the second phase of analysis, street and house area were considered separately.

Another major difference between the first and second phases of analysis was that much more elaborate interaction variables were used in the first phase. These were replaced by a single variable relating to the overall slope of flow, as it was found that equally good statistical explanation could be achieved using much simpler variables.

In both phases of analysis, separate versions of the regression were obtained for the cases in which special consideration was and was not given to "pre-war" residential development. It emerged during the analysis that older development--constructed before World War II--appeared to have a relatively low effect on the stream channel (see below).

RESULTS

The regression results are given in Tables 2 and 3. Regression coefficients which are statistically significant at the 5% level are underlined once; coefficients significant at 1% are underlined twice.

Each of the regression coefficients pertaining to a land-use variable represents the influence of the given land use on

Table 2

REGRESSION RESULTS: FIRST PHASE

		REGRESSION 1		REGRESSION 2	
		Pre-war area not considered separately		Pre-war area considered separately	
		Coeffi-cient	Standard Error	Coeffi-cient	Standard Error
X_1	Land in forest	-0.2691	.1043	-0.2869	.1007
X_2	Land in cultivation	0.1679	.1108	0.1704	.1070
X_4	Soil drainage score	-0.1128	.0291	-0.1076	.0281
X_5	Watershed shape index	-0.2817	.0877	-0.2587	.0847
X_{13}	Residential impervious area times street sewerage	2.0196	.4735	3.1522	.6723
X_{14}	Residential imperv. area times land slope	0.1799	.0846	0.1414	.8186
X_{15}	Pre-war resid. impervious area	----	----	-1.5937	.7131
X_{16}	Other imperv. area	4.7087	.3645	5.0017	.3829
X_{18}	Watershed-size interaction variable	0.2972	.0879	0.2459	.1042
X_{19}	Flow-to-channel Inter. variable	-1.9796	.7280	-1.3358	.6802
X_{20}	Flow-in-channel inter. variable	-0.1206	.0261	-0.1291	.0245
	CONSTANT TERM	1.6413		1.6003	
	MULTIPLE - R^2	.9813		.9829	

Table 3

REGRESSION RESULTS: SECOND PHASE

		REGRESSION 3		REGRESSION 4	
		Pre-war area not considered separately		Pre-war area considered separately	
		Coefficient	Standard Error	Coefficient	Standard Error
X_1	Land in forest	-0.1518	.1151	-0.2004	.1115
X_2	Land in cultivation	0.3896	.1291	0.3213	.1264
X_3	Land in golf courses	1.6416	.5538	1.2799	.5412
X_4	Soil drainage score	-0.1072	.0247	-0.0994	.0237
X_5	Watershed shape index	-0.1990	.0776	-0.1966	.0750
X_6	Area of sewered streets	3.2499	.8998	----	----
X_9	Area of post-war sewered streets	----	----	2.7429	1.0636
X_{10}	Area of pre-war sewered streets	----	----	1.9518	.9027
X_7	Area of houses fronting on sewered streets	0.8291	.7462	----	----
X_{11}	Area of post-war houses fronting on sewered streets	----	----	2.0392	1.2012
X_8	Other impervious area	3.7855	.4486	4.4797	.5388
X_{12}	Non-imperv. and unsewered resid. area	0.1870	.0890	0.1459	.0867
X_{17}	Slope-of-flow interaction variable	0.2966	.0350	0.2386	.0326
	CONSTANT TERM	1.4487		1.4575	
	MULTIPLE - R^2	.9813		.9829	

stream channel size, expressed in terms of the channel enlargement ratio. This influence is expressed as the difference between the effect on channel size of the given land use (land use being expressed as a proportion of watershed area) and the effect on channel size of "open land," which consists of land not forested, cultivated or otherwise developed and which is not included in any of the independent variables. The effect of "open land"--i.e., the value of the channel enlargement ratio for a watershed consisting entirely of open land--can be estimated from the regression results. It equals the constant term plus the means of the variables not involving land uses (namely the soil-score and watershed-shape variables) times their respective regression coefficients. The effect of open land is estimated at approximately 1.0 in the first phase of analysis, and approximately 0.9 in the second phase of analysis. Thus, a regression coefficient of 1.5 for some land use (say, in the second phase of analysis) would indicate that a watershed devoted entirely to this land use would have a channel enlargement ratio of equal to 1.5 + .9, or 2.4. The channel would be approximately 2.4 times the size which would be expected under normal conditions.

The situation is a bit more complicated for impervious land uses, however, due to the fact that these land uses also appear in weighted form in the interaction variables. Each of the interaction variables was based on an impervious area index which involved multiplying each of the land uses by a factor which was equal to the regression coefficient of the given land use when appearing as a separate variable in the regression. This index was formed for individual grid squares, then weighted by topographic or other watershed characteristics and summed over the whole watershed.

To continue the example give above, we may imagine a watershed in which the average slope of flow to the channel measurement point for all points in the watershed was equal to 2%. For an impervious land use with a regression coefficient of 1.5, the effect on channel enlargement of interaction of this land use with slope of flow would be equal to (1.5)(2)(0.29) = 0.87, where 0.29 is the regression coefficient obtained for the slope of flow interaction variable (in phase 2). Thus, the channel enlargement ratio associated with a watershed devoted entirely to this land use would actually be equal to .9 plus 1.5 plus 0.87 = 3.27. Ordinarily, of course, a watershed is not devoted entirely to a single land use, particularly an impervious use. Thus, effects are usually calculated on the basis of the proportion of watershed devoted to each use.

The largest effects obtained were associated with the "other impervious" category. For a watershed such as that described in the example above, complete coverage by "other impervious area" would result in a channel enlargement ratio equal to 0.9 + 3.8 + 3.8(2)(0.29) = 6.9. (This is close to the maximum increase in peak flows predicted by other investigators, as summarized by Leopold [1968].)

The results of the first phase differ greatly from the results of the second phase in that the first-phase results involve interactions between impervious area and specific flow components. These interaction effects are in the form of negative impacts on the influence of impervious area attributed to flow to channel and flow in channel, with these negative impacts increasing with distance of flow and decreasing with slope of flow. An important point is that the effects of drainage system alterations, namely the piping of flow-to-channel and flow-in-channel, are expressed as the absence of negative effects associated with these flow components. (Stream reaches in which the channel had been "improved," such as by lining the channel with some material, were treated as if half the length of channel had been piped.) In the second phase of analysis, none of the variables which proved significant incorporated any information regarding drainage alterations (other than the presence of street storm sewers).

The following paragraphs will consider each of the factors involved in the relationship between urbanization and stream channel enlargement.

Streets. Area of sewered streets appears to have a greater effect on channel enlargement than the area of houses, but a lesser effect than other impervious area. The effect of street area appears to be heavily dependent on the existence of storm sewerage. The first phase regressions attributed only a small effect to unsewered residential streets (through the interaction of residential impervious area with land slope); and the effect attributed to unsewered streets in the second-phase results was miniscule (this being the effect attributed to "non-impervious and unsewered residential land").

Houses. Houses appear to have the smallest effect upon channel enlargement of the three impervious land uses (although houses were not distinguished from residential streets in the first phase of analysis). This would presumably be due to the fact that each house constitutes only a small concentration of impervious area, so that the runoff leaving its surface represents only a relatively small concentration of flow and thus is likely to infiltrate into the surrounding pervious soil. As in the case of streets, the effect of house area seems to depend heavily on the existence of sewerage, with only a small effect attributed to houses not fronting on sewered streets. The importance of sewerage to the effects of street and house area may be somewhat exaggerated in the regression results, for various reasons. It is possible that there is an association between the extent of sewerage and the quality of sewerage, i.e., areas with low proportions of streets sewered tend to have relatively poor sewer systems for the remaining streets. This would give a downward bias to estimates of the effect of unsewered streets (and houses), and an upward bias to estimates of the effect of sewered streets.

Pre-war streets and houses. Houses and (residential) streets constructed before World War II were found, in the first phase of analysis, to have a significantly lower effect on channel enlargement than similar development constructed more recently. In the second phase, it was found that the difference between effects of pre-war and post-war homes was greater than the difference between effects of pre-war and post-war streets. The effect of post-war homes was in the vicinity of two, whereas the effect of pre-war houses was not found to be significantly different from zero. (Recall that "effect," as the term is used here, refers to the amount by which the influence of a given land use on channel size differs from the influence of "open land." An effect, or regression coefficient, of zero would imply that the land use in question has an influence on channel size equal to that of "open land.") It was initially hypothesized that the lesser effects attributed to pre-war development had to do with sewerage: the older residential areas in the sample either were provided with relatively poor sewer systems to begin with, or else have experienced deterioration of sewerage facilities due to clogging, etc., over time.

An alternative hypothesis was suggested by the results of the second phase, namely the possibility that the nature of the land surrounding older houses has changed over time. Due to the addition and growth of trees, shrubs, gardens, etc., the ability of the surrounding land to retain storm water may have increased, perhaps enough to nullify the effect of the house itself.

Other impervious area. Impervious area other than streets and houses was found to have the greatest effect upon channel size. The impervious area in this category consisted primarily of commercial and industrial buildings and their accompanying parking lots, although land uses as diverse as greenhouses and airport runways were also included. The most significant characteristic of this impervious area was the large average size of individual concentrations; nearly half of the area of this type in the sample watersheds was found in concentrations exceeding 5 acres in size (with each "concentration" consisting of a single building or shopping center and its accompanying parking lot). It was hypothesized that the great effect attributed to "other impervious area" was due to the large average size of impervious parcels, which would cause runoff to occur in large concentrations of flow so that subsequent infiltration or storage would be minimal. Rather surprisingly, no significant effect was observed for "other impervious area" weighted by the density of sewered streets. This may have been due to various spurious associations, however.

Land in golf courses. A quite large effect was attributed, in the second phase of analysis, to land in golf courses (excluding wooded areas between fairways). This effect was larger than that of any other non-impervious land use. The large effect could be due to the type of vegetation, the design of golf courses for maximum drainage, and the watering of fairways in summer months.

Average land slope. Average land slope, as observed for 40-acre grid squares, was found to have a significant positive influence on the effect of "residential" impervious area (i.e., houses and residential streets). This influence of land slope is illustrated in the diagram presented as Figure 2. The diagram uses iso- lines to indicate the effect of residential impervious area on channel enlargement for given values of land slope and proportion of streets sewered, based on the results of the first phase of analysis. The effects shown in the figure are comparable to regression coefficients, i.e., express effects in excess of the effect of open land. Thus, for example, the channel enlargement ratio for a watershed containing only residential impervious area might be calculated as follows (ignoring other factors such as flow-to-channel). If the watershed is 30% impervious, with 80% of its streets sewered and an average land slope of 10%, the per-unit effect of its impervious area would be 3.4 (from Figure 2), and its channel enlargement ratio would be: .9 + (.3)(3.4) = 1.9.

Watershed size. Watershed area was found, in the first phase of analysis, to have a negative influence on the effect of impervious area. That is, the effect of a given intensity and type of impervious development on the stream-channel enlargement ratio would be less, the greater the size of the watershed. This influence of watershed size is illustrated in Figure 3, which shows, for example, that a given percent coverage would have only 85% as much effect in a 5-square-mile watershed as in a 1-square-mile basin. The estimated influence of watershed size, while important, was somewhat smaller than had been hypothesized prior to the analysis. Watershed size was not attributed a separate influence in the second-phase regressions; this was also true for the flow-to-channel and flow-in-channel factors discussed in the next two paragraphs. The reason is that the overall-slope-of-flow variable used in the second phase subsumed all of these influences, including the influence of land slope (see below).

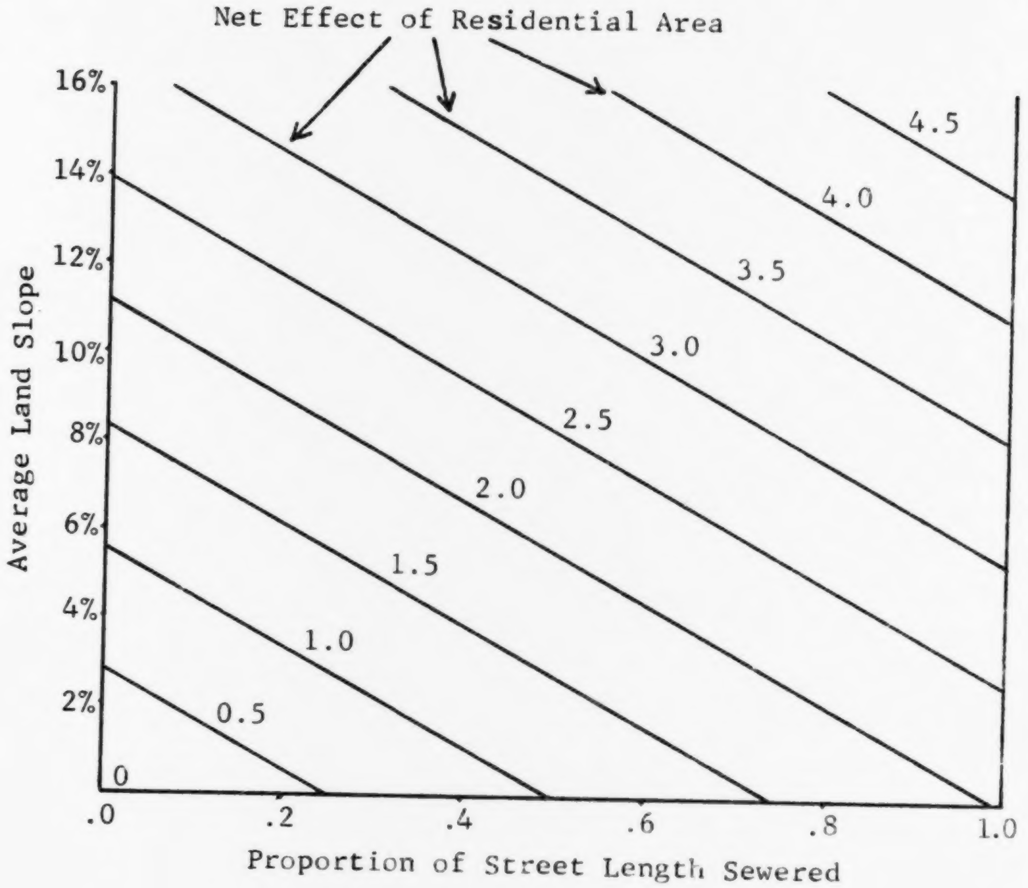


Figure 2

EFFECT OF RESIDENTIAL IMPERVIOUS AREA

Isolines express the effect of residential impervious area, over and above the effect of "open land," as a function of average land slope and proportion of street length sewered.

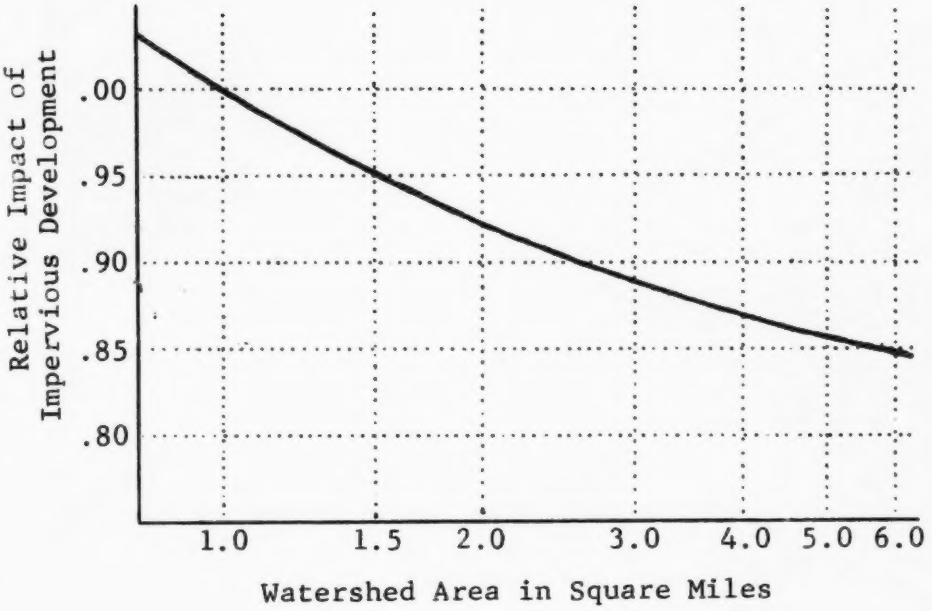


Figure 3

IMPACT OF IMPERVIOUS DEVELOPMENT RELATIVE TO THE IMPACT OF THE SAME TYPE AND INTENSITY OF DEVELOPMENT IN A 1-SQUARE-MILE WATERSHED

Flow to channel. For impervious development at a given location, the effect upon stream channel enlargement was found to be negatively related to the distance of flow to the stream channel and positively related to the average slope of this flow. The influence of flow to channel is illustrated in Figure 4, which gives the effect of impervious area for various distances and slope of flow-to-channel, relative to the effect of impervious area located immediately adjacent to the stream channel. For example, impervious area located one-half mile away from the stream channel with its flow path having an average slope of 2%, would have slightly less than 80% as much effect as impervious area located at the stream channel. The negative effect associated with flow-to-channel is considered to be absent when this flow component is piped. For the sample of watersheds studied the average distance to channel was only just over 1/4 mile and the average slope of flow to channel was approximately 2-3%. Thus, the average reduction in effect of impervious area (where this flow is not piped) was only about 10% (that is, the influence on impact as given in Figure 4 was about 90%). The smallness of this reduction of effect indicates that local restrictions on location of impervious development--such as prohibiting development within 300 feet of the stream--would have relatively little effect on peak flow magnitudes and channel enlargement.

Flow-in-channel. The effect on channel enlargement (at the channel measurement point) of impervious development at a given point in the watershed was found to be negatively related to distance of flow-in-channel and positively related to the slope of flow-in-channel. (Channel slope was expressed as an index in which it was adjusted for drainage area.) The influence of flow-in-channel is illustrated in Figure 5. As in the case of flow-to-channel, large negative influences on the effect of impervious development can occur when the distance of flow is great and when the slope is low; but the influence for average points in a typical watershed is fairly small. The average distance of channel flow for a one-square-mile watershed, for example, is about 3/4 of a mile, and the average value of the slope index is, by definition, 1.0, so that the typical reduction in effect of impervious area is only about 10%. For a watershed with channel slope typical of our sample, the overall location of development--i.e., whether it is concentrated near the measurement point or near

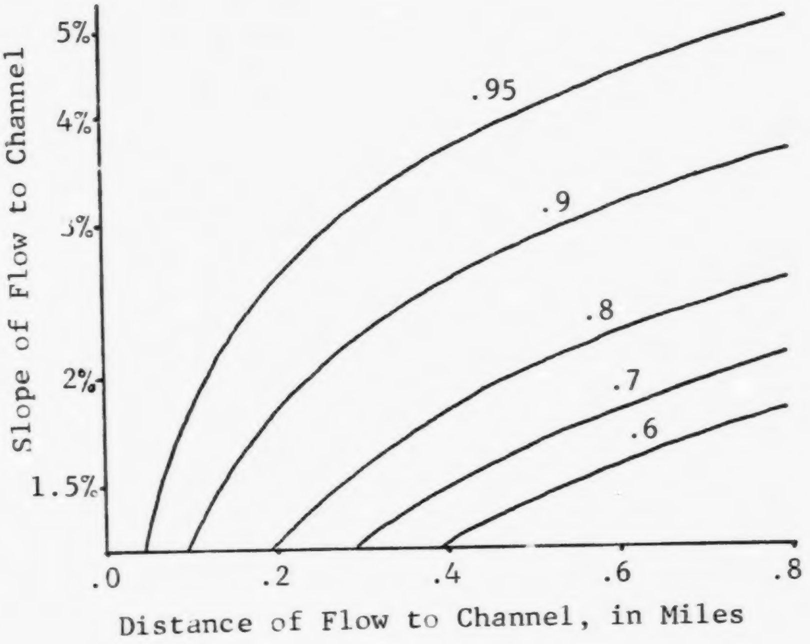


Figure 4

INFLUENCE OF FLOW TO CHANNEL

Isolines express the effect on stream channel cross-section area of impervious development located the given distance from the channel, having the given slope of flow to the channel, relative to what the effect would be were there no distance of flow to channel (i.e., were the development located adjacent to the channel, or were the flow path to the channel piped). The data pertain to a 1-square-mile watershed.

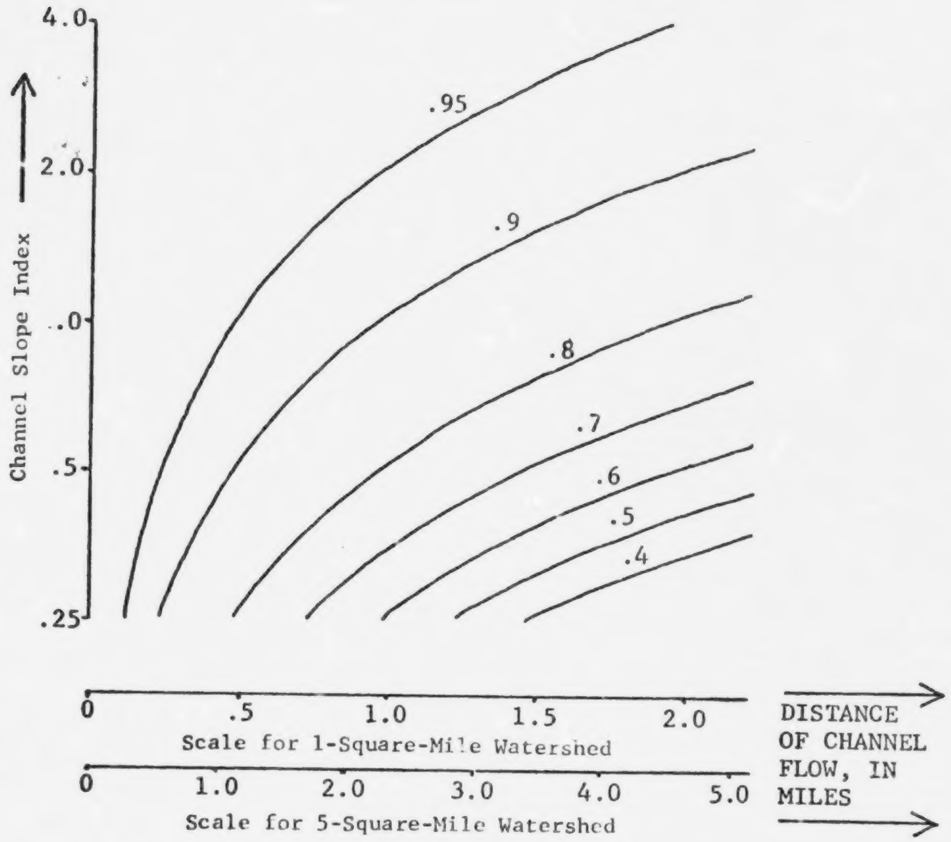


Figure 5

INFLUENCE OF FLOW IN CHANNEL

Isolines express the effect on stream channel area, at the channel measurement point, of impervious development located at a point for which the distance and slope index of intervening channel flow have the given values, relative to what the effect of the development would be were there no intervening distance of channel flow (i.e., were the development located at the channel measurement point, or were the intervening flow path piped).

the headwaters of the stream--does not seem to make a dramatic difference. Also, the piping of channels (which in our formulation eliminates the negative effect of channel flow) does not appear to be of particularly great importance.

Overall-slope-of-flow. In the second phase of analysis none of the previous four factors was expressed explicitly. Instead, the results included a single variable consisting simply of the average slope of the overall flow path from a measurement point. This variable, to which a strong positive effect was attributed, consisted simply of the difference in elevation by the length of the flow path between these two points. The important feature of this variable is that it is associated with most of the previous factors: negatively associated with watershed size and distance of flow-in-channel; and positively associated with land slope, slope of flow-to-channel, and slope of flow-in-channel. Thus this overall slope variable was able to capture the effects which were attributed in phase 1 to separate variables.

One major difference between the two sets of results, however, is the fact that no information pertaining to the piping of flow-to-channel and flow-in-channel is contained in the second phase results. The fact that equally good statistical explanation was obtained in spite of this omission could be due to the fact that such drainage alterations are closely associated with the extent of impervious development, so that the effects of the former were spuriously attributed to the latter in this phase. The second phase results make possible the simple calculation of the effect of development in a given basin, whereas the first phase results are more useful for planning purposes.

SUMMARY CONCLUSIONS

Location within a watershed. The results obtained concerning flow are generally consistent with the proposals of the Brandywine Plan, which would restrict development near the stream and on the steep slopes. The effects on stream flow and channel enlargement of development in these critical areas are probably less important, however, than the effects on erosion and sewage effluent. The most important consideration concerning stream flow and channel enlargement seems to be type of development. Whether or not a residential area is storm-sewered, for example, appears to make much more difference than its location relative to the stream. This suggests that serious consideration should be given to the possibility of purposely underdesigning storm sewer systems, providing catchment basins, or of finding some way to disperse the water which is collected by storm sewer systems.

Due to the large effect attributed to "other impervious area," it appears advisable to prohibit or severely restrict the construction of large parcels of impervious area such as shopping centers in watersheds which are to be protected.

Allocation of development among watersheds. It is clear that when there is a choice between allowing development in a steeply sloped watershed and a relatively flat watershed (referring to all aspects of slope including channel slope), development should be apportioned primarily to the less steeply sloped watershed. Also, it is apparent that location of development upstream of a relatively flat reach of channel can result in a considerable reduction of this effect, relative to its effect if located further downstream. Significant reduction of effect requires that the channel slope be quite gentle, however; and in addition, it must be remembered that location of development at upstream points will affect a larger length of stream channel. Therefore, the best general policy actually appears to be that of preventing development in the headwaters of streams. This would be consistent with the fact that the absolute amount of channel enlargement in square feet resulting from a given absolute amount of impervious development decreases markedly with increase in watershed area.

The equations developed in this study have been used to estimate the hypothetical effects of development at various sub-basins within the Brandywine Creek watershed upon the stream channel at all downstream points [Hammer, T. R., 1971, p. 279-314]. The amount of channel enlargement, in cubic feet, associated with one unit of development in a given sub-basin was then computed for all downstream points and summed to give a total impact figure. The lowest total impacts were obtained for sub-basins near the watershed mouth. These impacts were substantially lower than those calculated for the few sub-basins which lay upstream of relatively flat portions of channel. These results would tend to support a policy of preserving upstream portions of watersheds, as a means of minimizing overall environmental degradation due to urbanization.

III. EFFECT OF URBAN DEVELOPMENT ON STREAM WATER QUALITY

INTRODUCTION

It is generally accepted that urban development causes a deterioration in stream water quality. The effect, however, is not a simple one, and methods of predicting it are not well developed. Urban development is inherently complex since it includes a wide variety of activities, involving many types and patterns of physical development. In addition, the manner in which a particular activity or type of development causes change in water quality may itself be complex. For example, residential areas served by sanitary sewers may affect the stream in several ways: by contamination of ground water from scattered small leaks in the system; by more or less direct contamination of the stream by leakage of main sewers running along it; and finally by direct disposal of treated sewage into the stream. Because of the complexity of the phenomena, very few attempts have been made to make quantitative estimates of the effects typically associated with various amounts, locations, and types of urbanization.

This study represents an attempt to estimate, utilizing a large sample of watersheds with varying types and degrees of urbanization, the stream water quality effects typically produced by various types of urbanization. It is an attempt to see whether, despite the complexity of urbanization and the variability of water quality parameters, regularities can be observed between urbanization and stream water quality. Although the relationships can give only a general indication of how the effects are produced, they should be useful in providing some general direction for land use planners.

The study involved analysis of one water quality sample for each of a large number of streams. These samples were taken at the time of season low flow, and the results of the analysis refer to the effects of urbanization on base-flow conditions. The study has focused upon base-flow conditions because the concentrations of pollutants from urban sources are frequently highest at low flow, due to the minimal dilution of effluents which are introduced into the stream.

The contribution of street dirt and other surface debris to runoff and stream pollution has been documented [American Public Works Association, 1969]. Relationships between various characteristics of urban development and stream water quality at typical flow conditions has also been the subject of recent research by Economic Systems Corporation [July 1970]. Their findings indicate that stream water quality decreases with increasing population density and with the amount of development, particularly as measured by land devoted to streets, the type of streets, the amount of main covered storm sewer, and the ratio of covered storm sewer to total length.

The low-flow study conducted as part of this research project complements these two studies which refer to the effects of storm runoff in urban areas. Since only one set of chemical observations was made in the low-flow study, only those chemicals were investigated which were expected to be reasonably stable over time for a given stream. Therefore, many of the water quality parameters which are commonly considered most important, including dissolved oxygen, biochemical oxygen demand, and coliform count, were not investigated. A list of the chemicals studied is presented in the next section.

The sample of streams, all of which are located in the piedmont portion of the Philadelphia metropolitan area, consisted of watersheds ranging between 1 and 6 square miles in area. Due to the small size of the streams studied, the watersheds contained relatively few water-using industries. Therefore, the study focuses more on water pollution caused by human residence than on industrial pollution. Since only a few of the watersheds contained major sewage disposal facilities, the study may be said to deal primarily with "local" effects of urbanization, as opposed to overall effects which typically involve disposal of some or all sewage into bodies of water larger than the streams considered here.

The study was based on detailed urbanization data for each watershed, including direct counts of numbers of dwelling units. Most of the sample watersheds coincided with watersheds used in a related study of the effect of urbanization on stream channels which is summarized in Chapter II [Hammer, 1971].

DATA ON WATER QUALITY

Water quality samples were taken as part of this study for 58 streams on two consecutive days in September, 1969, at a time when there had been no rainfall in the area in several weeks. The samples thus represent water quality at "base flow." For all but two of the streams, discharge was less than one cubic foot per second per square mile of watershed area. In addition to the water quality data gathered explicitly for this study, water quality data for 10 watersheds were taken from an earlier study of Brandywine Creek [Institute for Environmental Studies, RSRI and USGS, 1968], which is also located in the piedmont portion of the Philadelphia metropolitan area.

Both sets of water samples were analyzed by the U.S. Geological Survey, which performed its standard analysis. The chemicals analyzed, with their means and standard deviations, are given in Table 4. An additional variable measured in connection with the water-quality samples was stream discharge, which was measured and recorded at the time each sample was taken.

For 8 of the 10 streams in the Brandywine area, more than one chemical sample was available. The total number of Brandywine samples was 46 (all representing base-flow conditions). Not all of these contained data for all of the chemicals, however; the number of Brandywine observations available ranged from zero (for dissolved solids--sum) to 46 (for chlorides). For most of the chemicals, the number of observations obtained from the Brandywine samples was between 15 and 30.

In addition, 7 of the 58 streams for which samples were taken as part of this study were deleted from the statistical analysis. These were omitted because of their tendency to "dominate" the statistical results, as is discussed below. Thus, the sets of observations used, to which the means and standard deviations given in the previous section apply, ranged between 51 and 97 in number. The number of obser-

Table 4

MEANS AND STANDARD DEVIATIONS OF CHEMICAL VARIABLES

	Units	Mean	S.D.
Chloride (Cl)	ppm	16.8	10.4
Sodium (Na)	ppm	10.8	4.9
Potassium (K)	ppm	3.2	1.3
Calcium (Ca)	ppm	21.6	8.9
Magnesium (Mg)	ppm	7.6	3.4
Hardness (Ca,Mg)	ppm	85.2	34.3
Hardness (non-carbonate)	ppm	40.0	21.4
Sulfates (SO_4)	ppm	30.3	17.0
Nitrates (NO_3)	ppm	11.2	7.8
Phosphates (PO_4)	ppm	.27	.64
Bicarbonate (HCO_3)	ppm	60.7	23.3
pH	-log H+	7.6	.40
Manganese (Mn)	ppm	.02	.04
Fluoride (F)	ppm	.23	.15
Iron (Fe)	ppm	.04	.03
Silica (SiO_2)	ppm	19.0	11.8
Total dissolved solids: sum	ppm	179.00	40.00
: residual on evaporation	ppm	160.00	59.00
: specific conduc.	micro mhos	298	72

Table 5

PRIMARY SOURCES OF CHEMICALS FOUND IN SURFACE WATERS

	Geologic Influence	Domestic Waste	Industry	Agriculture
Chloride	X	X		X
Sodium	X			X
Potassium	X			X
Calcium	X		X	
Magnesium	X			
Hardness	X	X	X	
Sulfate	X	X		
Nitrate	X	X	X	X
Phosphate		X		X
Bicarbonate	X		X	
pH	X			
Manganese	X			
Fluoride	X		X	
Iron	X		X	
Silica	X			
Total diss. solids	X	X	X	X

vations used for each chemical is given below with the statistical results.

The following table summarizes very briefly the primary sources of each chemical, as found in surface waters. The purpose of the table is to indicate in a rough way which chemicals one might expect to be correlated with indices of human activity.

Geological influence is mentioned for all the chemicals except phosphates. A number of the chemcials, such as manganese and silica, are commonly thought to be primarily geological in origin. With regard to the chemicals for which more than one source is indicated in Table 5 (above), many of these are known to be contained in the effluents from various activities, but the relative importance of human versus geologic influence is difficult to specify.

PREPARATION OF WATERSHED VARIABLES

All of the variables used to "explain" the observed chemical concentrations were, with the exception of stream discharge, variables relating to watershed conditions, primarily conditions relating to human occupancy and activity. These variables were all prepared using a watershed grid system, with grid squares 40 acres in size. The values of the quantities in question were measured and recorded for each individual grid square, and then summed over the entire watershed. In some cases, variables were weighted by other quantities observed for individual grid squares, before being summed.

The watershed data for this study were prepared in conjunction with data for the study of effects of urbanization on channel enlargement. Although the latter study was concerned with somewhat different variables, in particular the amounts of various types of impervious area, there were several variables which were employed in both studies. The following table contains a list of the quantities measured for each grid square, and a statement of the "basic variables" computed from these. The basic variables pertain to whole watersheds; each involves a summation (denoted by "Σ") of some quantity over all grid squares. The paragraphs which follow then discuss the various quantities in detail.

Table 6

WATERSHED DATA

Quantities measured for each grid square:

X_0	Area of grid square (in square miles)
X_1	Total population of grid square
X_2	Proportion of grid square population served by sanitary sewer system involving disposal of effluent within the watershed
X_3	Proportion of grid square population served by sanitary sewer system involving disposal of effluent outside the watershed
X_4	Proportion of dwelling units in grid square built before 1940
X_5-X_8	Manufacturing employment in grid square, by 4-digit SIC code (up to 4 industries)
X_9	Land area in cultivation (in square miles)
X_{10}	Land area impervious (in square miles)
X_{11}	Average soil score for grid square (1-4 scale)
X_{12}	Average distance of land in the grid square from the stream channel (in feet)

Basic variables computed for watersheds:

Postwar population sewered out: $\Sigma X_1X_3X_4$

Prewar population sewered out: $\Sigma X_1X_3(1-X_4)$

Population sewered in: ΣX_1X_2

Population unsewered, no gradient: $\Sigma X_1(1-X_2-X_3)$

Population unsewered, 2,000' gradient: ΣK
where $K = X_1(1-X_2-X_3)(1-X_{12}/2000)$ if $X_{12} < 2000$, and $K = 0$ otherwise. (Similarly for variables incorporating 1500-foot and 1000-foot gradients.)

Average soil score: $\Sigma X_1 X_{11}/\Sigma X_1$

Land in cultivation: ΣX_9

Percent of watershed impervious: $\Sigma X_{10}/ \Sigma X_1$

Total manufacturing employment: $\Sigma (X_5 + X_6 + X_7 + X_8)$

Manufacturing employment figures for subcategories, including individual SIC groups and a single "high water-using and water-polluting industries" category, were also prepared, by simple summation of the relevant quantities.

Area and total population of grid square. Total population of each grid square was estimated by counting the number of single-family houses from aerial photographs, and determining in the field the number of dwelling units in multi-family structures by counting mailboxes. A total population figure was obtained by multiplying the number of single-family dwellings by 3.6 and the number of dwelling units in multi-unit structures by 2.4 (figures based on average conditions in the study region), and summing these two components.

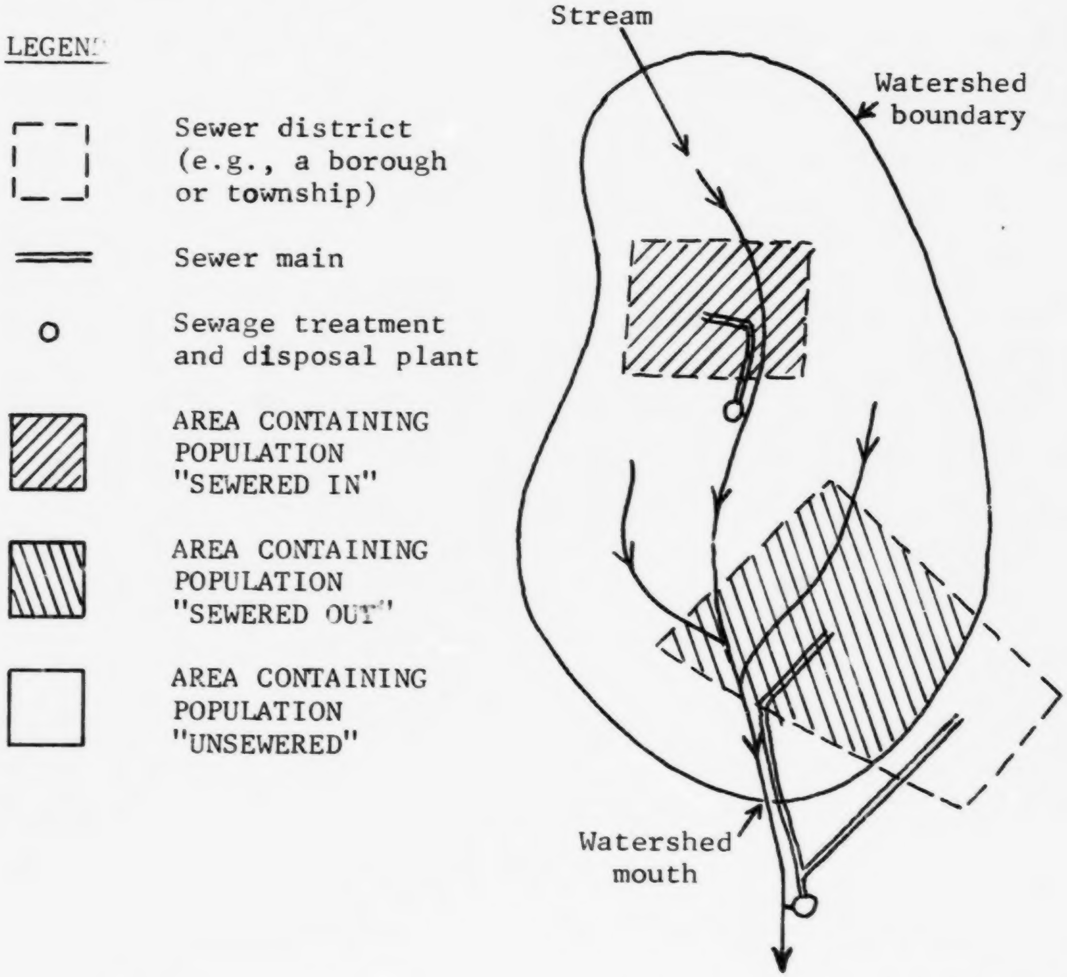
Proportions of population "sewered in" and "sewered out." A factor which was considered to be of primary importance was existence of sanitary sewerage. In this regard, a significant factor was whether or not the treated effluent yielded by a sewer system was disposed of inside or outside of the watershed in question. For small urbanized watersheds, a typical situation is that the sewage from most dwelling units is exported from the watershed, frequently by sewer mains running alongside the stream, and disposed of at some downstream point. In such a watershed, the sewage produced by the resident population can only affect water quality insofar as there is leakage from the sewer system within the watershed. On the other hand, some watersheds contain the disposal facilities themselves. Sewage from dwelling units served by these facilities affects water quality both by the content of the effluent from the disposal plant and by leakage from the sewer system.

In this study, population in dwelling units served by sewer systems which export sewage from the watershed for disposal elsewhere is referred to as "population sewered out." Population in dwelling units served by sewer systems which involve disposal within the watershed is termed "population sewered in." It should be noted that this distinction is merely a result of our choice of stream measuring points; the population "sewered out" for a given watershed will almost invariably be "population sewered in" for another measuring point. Population "sewered in," "sewered out," and "unsewered" are illustrated below in Figure 6.

It will be noted that population in dwelling units outside a watershed may be relevant to water quality in the watershed if it is served by a sewer system which involves disposal

Figure 6

ILLUSTRATION OF POPULATION "SEWERED IN," "SEWERED OUT," AND "UNSEWERED"


LEGEND
Sewer district (e.g., a borough or township)
Sewer main
Sewage treatment and disposal plant
AREA CONTAINING POPULATION "SEWERED IN"
AREA CONTAINING POPULATION "SEWERED OUT"
AREA CONTAINING POPULATION "UNSEWERED"
Stream
Watershed boundary
Watershed mouth

within the watershed. This complication arose in only two of our watersheds, both of which were eliminated from the sample for statistical reasons.

Sewerage information for the sample watersheds was obtained from the excellent maps provided by the Delaware Valley Regional Planning Commission. The data recorded for each grid square consisted of estimates of the proportions of the population in the square which were sewered out or sewered in. These proportions were either 0 or 1 for the great majority of grid squares.

Proportion of dwelling units in grid square which were built before 1940. It was reasoned that leakage from sewer systems might typically increase over time. Although it was impossible to obtain data relating to age of sewer lines themselves, it was thought that this age should be highly correlated with age of dwelling units. Therefore, utilizing U.S. Census of Housing information for census tracts plus aerial photographs, an estimate was prepared of the proportion of dwelling units in each grid square which were built before 1940. These are hereafter referred to as "pre-war dwelling units."

Manufacturing employment. All manufacturing establishments in the sample watersheds were noted in the course of the field survey. Then an industrial directory was used to determine the employment of each establishment and its classification according to the Standard Industrial Classification (SIC) detailed (4-digit) code. The employment of each establishment and its SIC code were recorded by grid square. (There were never more than 4 establishments in a given grid square; therefore, this information is denoted by four employment variables, X_5 through X_8).

Land area in cultivation. Land in cultivation is defined as land that was under tillage at the time the air photographs were taken. This variable was measured for each grid square using the aerial photographs; it was not considered feasible to conduct field surveys for this purpose. This variable was rather unsatisfactory in expressing the overall impacts of agriculture on water quality, due to the fact that it provides no indication as to the intensity of cultivation or the number of livestock being grazed.

Land area impervious. The area of land in each grid square covered by impervious surface, such as streets, buildings, parking lots, etc., was measured using aerial photographs and field survey, as part of the channel enlargement study.

Average soil score. This variable, which was originally prepared for the channel enlargement study, expresses the drainage characteristics of the soil on a one-dimensional scale. Each of the soil types mapped by the Soil Conservation Service [1963] is described as being either "well drained," "moderately well drained," "somewhat poorly drained," or "poorly drained." In forming a one-dimensional scale, "soil scores" of 4, 3, 2, and 1 were assigned to soils having the above descriptions, respectively. The average soil score for each grid square was computed by averaging the scores for soil types found at four randomly located points within the grid square.

Average distance of grid square from stream channel. The average distance of flow from each grid square to stream channel was estimated by measuring the distance from the central point of the square to the channel along a line running perpendicular to the topographic contour lines (i.e., the most probable course of surface or sub-surface flow). Occasionally, a situation was encountered in which portions of a given grid square would drain in quite different directions. In such cases, the distance to channel was obtained as a weighted average of two or more distances measured separately.

The computation of each of the basic variables pertaining to population was accomplished by multiplying total population in each grid square by one or more factors of proportion, relating to sewerage and/or age characteristics of housing in the grid square, and summing over grid squares. It was known that the straightforward use of proportionalities would involve errors for individual grid squares; for example, a grid square with 50% of its housing sewered out and 50% of its housing pre-war need not have approximately 25% of its housing "pre-war sewered out." However, the errors should cancel whole watersheds.

As indicated in Table 6, the basic variables relating to population were· population in post-war dwelling units sewered out, population in pre-war units sewered out, population in units sewered in, and population in unsewered dwelling units (in various forms; see below). Pre-war and post-war dwelling units "sewered in" were not considered separately since leakage from sewer lines was presumed to account for only a minor portion of the effect produced by these units (i.e., minor relative to the effect produced by the effluent disposed directly into the stream).

It was thought that the distance of dwelling units from the stream channel might be particularly important for unsewered units whose sewage is disposed of in the soil. The distance from the dwelling unit to the stream would represent the distance within which the purifying action of the soil might remove contaminants originating at the dwelling unit. Thus several "gradient" forms of the variable involving unsewered dwelling units were prepared, which attributed lower effects to dwelling units farther from the stream. In each case, a linear form was used, with the effect reaching zero at a specified distance. For example, in the "2000-foot gradient" variable the effect of a house adjacent to the stream would be 100%, the effect of a house 1000 feet from the stream would be 50%, and the effect of a house 2000 feet or more from the stream would be 0%.

Variables incorporating 2000 feet, 1500 feet and 1000 feet as the zero point were tested. The 2000-foot gradient variable was almost always more significant in explaining chemical concentrations than either of the variables incorporating shorter gradients. Thus, in the discussion which follows only the 2000-foot gradient variable is mentioned.

Numerous variables were prepared and tested which related to manufacturing employment. These included sums of manufacturing implyment for individual standard industrial classifications, and also a variable expressing total manufacturing employment. In addition, a vairable was prepared expressing the sum of employment in certain industries which are considered to be high water-using and high water-polluting industries [Isard and Romanoff, 1967, pp. 7-10, 21-22].

FORM OF THE ANALYSIS

As described above, the collection of watershed data was quite straightforward. Each basic variable for a watershed consisted of a magnitude--e.g., manufacturing employment, or population in dwelling units having a certain type of sewerage--summed for the watershed as a whole. It was recognized, however, that the basic form of the variables was not appropriate for the job of explaining the concentrations of chemical constituents in stream waters. In order to obtain meaningful results, it was necessary to "scale" these absolute magnitudes by other factors, such as watershed size, which would be expected to interact with these magnitudes in determining stream conditions.

The importance of watershed size arises from the fact that one generally would expect the density of development in a watershed to be more relevant than the absolute amount of development in determining water quality. For example, a stream draining a one-square-mile basin containing 10,000 people would be expected to have higher concentrations of urbanization-related chemciais than a stream with a 100-square-mile watershed containing 10,000 people; the former is "urban" whereas the latter is not. Thus, each of the basic land-use variables was transformed by dividing it through by watershed area (i.e., the value for each stream was divided by watershed area for that stream). This yielded variables of the form: population per square mile, manufacturing employment per square mile, etc.

The transformation of land-use variables to a per-area basis is quite common in all sorts of research, and usually goes without comment. In this study, however, a similar transformation was also made using another factor, which resulted in variables of a less familiar nature.

This second factor was stream discharge, measured at the time the chemical samples were taken. Since all the samples were taken at base flow, discharge was fairly highly correlated with watershed area; but the correlation was far from perfect. The use of discharge rather than watershed area to "scale down" the land-use variables would be appropriate in certain circumstances such as the following: Suppose that there is a source such as a factory which introduces some chemical to a stream at a constant rate; and suppose that this is the only major source of that particular chemical in the watershed. Then the concentration of that chemical in the stream would be determined by the discharge of the stream, i.e., by the extent to which the chemical received is diluted by the water in the stream.

When dealing with a chemical for which this general sort of situation is felt to be typical, a possible mode of analysis would be to multiply the observed concentration of the chemical times the stream discharge, to yield a figure for the absolute amount of the chemcial being discharged by the stream. This figure would then simply be related to a variable expressing the absolute magnitude of the suspected source of the chemical. That is, the relationship being investigated would have the following form:

$$CD \propto X$$

where C = observed concentration of the chemical in question in the stream

D = stream discharge

X = magnitude of the source (or some surrogate variable; e.g., employment in a certain manufacturing industry)

Since it is generally more convenient to retain the dependent variable in the form of a chemical concentration, the following sort of relationship was employed in this study (which relationship is obtained from the above by dividing by discharge):

$$C \propto \frac{X}{D}$$

Thus, a second set of independent variables was derived in which each of the basic magnitudes, such as population in a given type of dwelling unit, was divided by discharge.

One will note that the form of variables involving division by discharge should be the more relevant for "point" sources of pollution, and the form involving division by watershed area should be more relevant to "area" sources. For point sources, at which contaminants are introduced more or less directly into the stream, the only important factor would be the amount of dilution (as discussed above). For area sources, which tend to involve contamination of the groundwater at points located more or less randomly throughout the watershed, the important factor would be watershed areas, which determine "how much" groundwater is involved and hence determine the intensity of contamination. Stream discharge, which is related to the rate of outflow from groundwater storage, would be important for area sources only to the extent that chemical concentrations in the groundwater are correlated over time with the rate of outflow.

These two forms of the independent variables were thus intended to embody two archetypes of possible ways in which chemical concentrations might be determined. As such, they were taken to represent "extreme cases." Therefore, it was felt that an additional set of independent variables should be formulated which expressed an intermediate case, in which the effect produced by a source of a given magnitude would depend on both watershed area and discharge. This intermediate form was obtained by calculating the geometric mean of watershed area and discharge, and using this as a divisor for the magnitudes of the various pollution sources.

Thus, for each of the basic variables discussed in the previous section (except the "soil score"), three independent variables were prepared:

"Density form" X_{ij}/A_i

"Discharge form" X_{ij}/D_i

"Mixed form" $X_{ij}/(A_i D_i)^{\frac{1}{2}}$

where X_{ij} = magnitude of pollution source j in watershed i (e.g., some component of population or employment)

A_i = area of watershed i in square miles

D_i = discharge of stream i at the time the sample was taken, in cubic feet per second

In the analysis, the procedure was not to make an a priori judgment as to which form of a variable would be most appropriate for a given chemical. Rather, the plan was to see which form would prove most successful as an independent variable in the regression analysis.

The results obtained, with regard to which of the three forms is most successful for a given source and chemical, have been rather interesting. However, in interpreting these results, one must keep in mind the following facts: First, the statistical tests which were carried out related only to the "significance" of each variable in itself, not its significance *vis à vis* other forms; thus, no confidence level can ben attached to the choice of one variable over another. And second, there are actually a number of reasons why one form might be more successful than another, not involving the behavior of "point" sources versus "area" sources as discussed above.

ANALYSIS AND RESULTS

Preliminary Analysis

The procedure followed in this study was to attempt to explain each of the water quality variables statistically using multiple regression analysis. Except in the preliminary phase of analysis, each of the basic watershed variables was entered in the regression in three forms as discussed in the previous section. (This was not true for the soil score variable.)

A computer program for stepwise regression was utilized in the analysis. However, considerable experimentation was conducted for each of the chemicals, in the form of forcing independent variables into, or deleting variables from, the regression, so that the results do not necessarily represent simply the "stepwise solution."

An extensive preliminary analysis was conducted, utilizing both the full sample of streams (for a given chemical) and also samples with some of the streams deleted. A major outcome of the preliminary phase of analysis was the finding that it was not possible to utilize the information concerning manufacturing employment at the level of detail which was available. The reason for this was that a given 4-digit industrial category [Bureau of the Budget, 1967] would typically be represented in only one or two watersheds; or at least, the employment in one or two watersheds would be highly dominant. This problem was encountered even when the manufacturing data were aggregated to the 2-digit standard industrial classification level. Therefore, it was decided simply to use two summary variables, namely, total manufacturing employment and total employment in high water-using and water-polluting industries.

It is recognized that the results obtained for these two variables can be attributed only very general significance. That is, a positive coefficient obtained for, say, total manufacturing employment indicates only that perhaps one industry in ten or one industry in a hundred is actually contributing the effluent in question. This would have been a problem regardless of the level of detail employed, but it is clearly worsened by aggregation.

A second major consideration which was dealt with in the preliminary analysis was the problem of heteroscadasticity, i.e., dominance of the regression by a few observations. This problem occurs when one is dealing with variables having skewed distributions: typically, most of the values of the observations are small but a few are relatively large. (Technically, heteroscadasticity refers to certain characteristics of the "error term" of a regression, rather than the distribution of the dependent variable *per se*; but a highly skewed dependent variable will almost always imply heteroscadasticity.) The difficulty is that under these circumstances the regression will be inordinately influenced by the values of the "large" observations. This means that the chance of erroneous results is increased because the results are being determined by so few observations.

An extreme example of heteroscadasticity is provided by the case of phosphate concentrations as measured in this study. For the full sample of streams, the variation (i.e., sum of squared deviations around the mean) in phosphate concentrations was greater than 800. Removal of two of the 80 observations reduced the variation to 43. Clearly, the regression would be totally dominated by these two observations; any factor which explained the deviation of one or both of these from the mean would be found highly "significant."

It was found that the streams whose observations were dominant tended to be the same for most of the chemicals. Thus, it was decided to deal with heteroscadasticity by eliminating certain streams in all of the analyses. At first, two streams were eliminated. When heteroscadasticity problems were found to persist, five more streams were eliminated. Of the seven streams eliminated, five contained major sewage disposal facilities; in addition, five contained major concentrations of industry. The water quality data for these omitted streams are presented and discussed below in this section.

In the initial phases, the soil score variable was not included in the analysis. Two related variables which were included were: stream discharge, and discharge per watershed area, both in simple form (i.e., neither was being used to weight some other factor). The latter of these, discharge per watershed area, was found to be significantly related to many of the chemicals. This occurrence led to speculation as to whether the importance attributed to discharge *per se* was due either to some action of discharge itself or was instead an indirect reflection of permanent watershed characteristics, such as those related to geology. Thus, it was decided to test the soil score variable, which was available from the earlier channel enlargement study and which measured soil drainage characteristics, as described in the previous section. The outcome was that the soil score variable was attributed major significance for many of the chemical variables, greater than the significance formerly attributed to discharge per watershed area. Thus, the soil score variable was allowed to replace the discharge-per-watershed-area variable in the regressions.

One rather disappointing, but not unexpected, outcome of the analysis was the failure of land in cultivation to appear as a significant explanatory variable in all but one of the regressions. (This was a regression for bicarbonates, which is listed separately below. A significant relationship involving agriculture was also found for nitrates, using a special sub-sample of observations.) The general non-significance of land in cultivation was due both to inadequacies of the variable as a measure of agricultural activity, and to statistical factors involving the strong negative correlation between land in cultivation and the urbanization-related chemical sources.

The percent-of-watershed-impervious variable, when tested, was marginally significant for several of the chemicals. However, the appearance of this variable as an explanatory factor seemed to be due just to its close association with other aspects of urbanization, rather than any causal relationships involving impervious area itself; thus this variable was deleted from the analysis. Neither land in cultivation nor percent-of-watershed-impervious area are mentioned in the tabular summaries of regression given in the next subsection.

Results as a Whole

Following the preliminary analysis described above, in which the statistical sample was adjusted and various decisions were made with regard to invidual variables, a "final" set of regression results was obtained. In these regressions, the urbanization variables were allowed to enter in whatever form worked best--i.e., whether the basic quantity was divided by watershed area, discharge, or the geometric mean of these quantities.

In a few cases, more than one form of an independent variable would enter the regression at a given time. For example, a variable might enter in "discharge" form with a positive coefficient, and also in "density" form with a negative coefficient. In such cases, the weaker form of the variable was suppressed (this was always the one with the negative coefficient). However, the "unsewered houses" variable was allowed to enter both in 2000-foot gradient form and in the form with no gradient.

Since considerable experiementation was carried out after obtaining the stepwise regression solution, the results should be near the "best" results obtainable. However, no formal test was applied to assure that the results were, in fact, best according to some statistical criterion.

This set of regression results is summarized in Table 7. The table lists only the forms of independent variables which were significant in the regression, and not the actual coeffi-

Table 7

SUMMARY OF REGRESSION RESULTS: UNFORCED REGRESSIONS

Form of Independent Variable and Significance Level

Chemical	Soil Score	Sewered Out Postwar	Sewered Out Prewar	Sewered In	Unsewered 2000 ft. Gradient	Unsewered No Gradient	Manufacturing Employment Total	Manufacturing Employment Effluent-Related Industries	R^2	n
Cl	x	Density	Mixed	Mixed	Density		Density		.68	97
Na	x		Mixed	Density		Mixed	Density		.71	71
K	x	Density	Density	Density					.53	61
Ca	x		Mixed	Mixed	Mixed		Mixed		.80	84
Mg	x	Density	Mixed		Mixed				.60	84
Hardness (Ca,Mg)	x	Density	Mixed	Mixed	Mixed		Mixed		.80	84
(non-carb.)	x	Density	Density		Density				.55	73
SO_4	x		Mixed						.64	81
NO_3		Density		Density	Density				.35	85
PO_4			Disch.	Mixed					.91	73
HCO_3			Density	Mixed	Mixed	Disch.		Disch.	.65	74
pH	x								.24	76
Mn							Density		.19	60
F							Density	Mixed	.29	61
Fe				Density		Mixed	Density		.48	60
SiO_2					Disch.				.16	61
TDS:SUM	x		Disch.	Mixed	Density		Density		.57	51
R.O.E.	x		Mixed	Mixed	Density		Density		.77	76
Specific Cond.	x		Mixed	Mixed	Mixed		Mixed		.66	51

All listed variables are significant at the 0.05 level; underlined variables are significant at the 0.01 level.

cients obtained. Variables significant at the 1% level are underlined. Significance of the soil score variable is indicated by an "x."

The level of statistical explanation for most chemicals was fairly high, perhaps suprisingly high, in view of the fact that the determination of many of the chemical concentrations is commonly considered to be geological. For 13 of the 19 chemicals, more than half of the total variation was explained by the significant independent variables in the regression. The average value of R^2 was 0.56.

An interesting feature of the regression results, when viewed as a whole, is the considerable similarity in the forms of the independent variables which best explained the various chemcials. For population in post-war dwelling units sewered out, the density form was chosen in all six cases where the variable was statistically significant. For the other four variables involving population, the mixed form was more prevalent. The totals were as follows: for "pre-war sewered out," there were 8 in mixed form, 3 in density, and 2 in discharge; for "sewered in," there were 9 in mixed form, and 3 in density; and for "unsewered," including both 2000-foot gradient and no gradient versions, there were 7 in mixed form, 5 in density form, and 1 in discharge form. For total manufacturing employment, the density form was prevalent.

It is difficult to compare the results for various chemicals when the form of the independent variables differs among chemicals. Since it was recognized that a variable might work nearly as well in one form as in another, it was decided to rerun the regressions forcing each independent variable into a common form. The form chosen in each case was the form most prevalent in the set of regression results listed in Table 7. As theoretical justification for forcing into a common mold the explanation of a wide variety of chemicals, one may argue that the relative importance of the various forms of the variables had to do primarily with the manner in which effluent from a given source reaches the stream. The hypothetical description on point and area sources given earlier in this chapter, for example, might apply equally well to a wide variety of chemicals.

An additional change made in the regressions was that the unsewered no-gradient variable, which was found significant for only three chemicals, was eliminated from the regressions. This was done in the interest of greater uniformity of results; it was suspected that the 2000-foot gradient variable would serve nearly as well in these cases.

This second set of "final" regression results is presented in Table 8, in which the actual regression coefficients are given. The average value of R^2 for these regressions is 0.54, down only 0.02 from the previous set. Still interpreting the regression results as a whole, there is a very interesting overall pattern of regression coefficients. (The reader should note that a coefficient which is not included in the table does not necessarily have a value of zero; such coefficients simply have failed to prove statistically significant. Thus, in comparing regression coefficients for different regressions, it is best to consider only pairwise comparisons between variables which are both significant.)

The coefficients obtained for the sewered-in variable and the unsewered 2000-foot gradient variable tended to be similar, with some variation. For each of the 9 chemicals for which both variables were significant, the coefficient for one of these variables never exceeded twice the coefficient of the other. The coefficients for pre-war sewered-out were much lower than these, with values lying between 1/14 and 1/4 the size of the coefficients for the sewered-in and the unsewered gradient variables (except in the case of phosphates). Finally, the coefficients for post-war sewered-out tended to be lower than for pre-war sewered-out. Although these coefficients cannot strictly be compared due to the fact that these two independent variables are in different forms, it is possible to make a general comparison by noting that, given the average values of discharge and watershed area observed in this sample, the effect expressed in a mixed-form variable is roughly twice the effect expressed in a density-form variable (since the denominator in the latter variable is on the average twice as great). Thus, the post-war-out coefficients should be divided by a factor of approximately 2 for comparison with the others. This would indicate that population in post-war dwelling units sewered out tends to

Table 8

SUMMARY OF REGRESSION RESULTS: FORCED REGRESSIONS

	Independent Variable								
	Constant Term	Soil Score	Sewered Postwar	Out Prewar	Sewered In	Unsewered 2000 ft. Gradient	Manuf. Total	Employment Effluent-Related Industries	R2
Form of Indep. Variable	----	----	Density	Mixed	Mixed	Mixed	Density	Mixed	
Cl	28.126	-5.76048	.00230	.00196	.02253	.02652	.00701		.69
Na	19.840	-3.99000		.00143	.01726	.00867	.00285		.70
K	5.228	-.90732	.00042		.00329				.42
Ca	42.405	-8.73838	.00124	.00223	.01710	.02487	.00481		.80
Mg	15.125	-3.07161	.00051	.00101		.00871			.60
Hardness (Ca,Mg)	162.119	-32.76747	.00480	.00992	.05833	.10216	.01448		.80
(non-carb.)	102.374	-22.94466	.00453	.00357					.52
SO_4	97.74	-23.08936		.00533					.64
NO_3	8.390		.00223		.02355				.29
PO_4	.0637			.00008	.00592				.90
HCO_3	77.380	-11.55862		.00730	.05735	.8532	.00789	.16622	.63
pH	8.879	-0.43112							.24
Mn	.01591						.00003		.19
F	.190						.00008	.00164	.29
Fe	.0199				.00008	.00008	.00003		.46
SiO_2	16.492					.02290			.07
TDS:SUM	227.010	-28.42377		.01335	.10598	.07807	.02421		.59
R.O.E.	269.115	-50.06776	.00729	.01852	.12656	.14554	.02750		.79
Specific Cond.	419.137	-61.45015		.02312	.14420	.10722	.04635		.62

All listed coefficients are significant at the 0.05 level; underlined variables are significant at the 0.01 level.

have between 20% and 60% as much effect on water quality as population in pre-war units sewered out, and between 2% and 7% as much effect as population in sewered-in or unsewered dwelling units.

These relationships between coefficients are quite in accordance with expectations. Population in post-war dwelling units which are sewered out of the watershed would be expected to have the lowest effect, since the only effluent reaching the stream would be leakage from sewer pipes which have been fairly recently constructed. Population in pre-war sewered-out dwelling units would be expected to have a higher effect since leakage would probably have increased over time. Population in unsewered dwelling units and dwelling units sewered to disposal plants in the watershed would be expected to have much higher effects since large amounts of effluents are added directly to the groundwater/surface-water system of the watershed under study. In both cases there may be considerable purification of effluents, by the soil in the case of houses with septic systems, and by direct treatment in the case of effluent passing through disposal plants. However, the potential effect upon stream water quality would obviously be much greater than for dwelling units sewered out of the watershed.

With regard to the forms chosen for the population-related variables, the use of density form for the post-war-out variable would be reasonable if one assumed that leakage from relatively new sewer systems tend to involve only small local leaks which are randomly located throughout the watershed, as opposed to leakage from sewer mains running along the stream. This situation would suggest a "density" effect as discussed above. A similar argument could be given, however, with regard to unsewered dwelling units. The fact that the unsewered-gradient variable tended to be slightly more successful in mixed form than in density form may be due to the incorporation of the distance-to-stream gradient, which gave greater weighting to some extent with a dilution effect. The use of mixed form for population in pre-war dwelling units sewered out is logical if it is true that the sewer leaks which develop over time tend to involve sewer mains which run along the stream. Finally, the use of discharge form is most logical for population sewered to disposal points in the watershed, if it is the case that the volume of treatment plant effluent is uncorrelated with stream discharge at base flow. In any case, the use of mixed form, which does incorporate discharge, is more logical than the use of density form.

A somewhat surprising result of the analysis was the fact that the variable expressing total manufacturing employment proved significant for many more chemicals than the variable expressing employment in high water-using and water-polluting industries. This result may be due more to the inadequacy of the latter variable than the strength of the former variable.

To some extent, the significance of the total manufacturing employment variable may be attributed simply to human presence, i.e., to the production of domestic-type sewage by manufacturing employees. This would be consistent with the use of the manufacturing variable in density or mixed form rather than discharge form, since industries are unlikely to discharge domestic-type effluent directly into a stream.

The manufacturing employment variable was the only information in the study concerning non-residential human presence. The suggestion that such presence per se may be an important influence on stream water quality indicates that it might have been worthwhile to have a total employment variable for each watershed. Data on non-manufacturing employment (or some other index of human presence) would have been much more difficult to obtain, however. A second weakness of the study in this regard was the fact that manufacturing employment was not categorized by type of sewage facilities available in the area, as was done for residential population.

On the whole, the strongest of all the independent variables was the "soil score" variable; this was significant at the 1% level for 13 of the 19 chemicals. In general, soil characteristics are expected to be important since they relate both to the capacity of soils to filter and purify effluents in the water passing through the soil, and to chemicals in stream water which originate from the soil; i.e., the geologic influence on stream water quality. As described earlier, the soil score variable measures in a rough way the drainage characteristics of a soil, with scores ranging between 4.0 for a "well-drained" soil and 1.0 for a "poorly drained" soil as described by the U.S. Department of Agriculture's soil survey. The results obtained from this variable indicate in every case that higher chemical concentrations in stream water are associated with lower values of soil score, that is, with more poorly drained soils. This result is difficult to interpret for two reasons: first, because it is impossible to determine to what extent the effect is actually due to drainage and to what extent it is due to geologic factors; and second, because it is not entirely clear how soil drainage characteristics relate to the average amount of purification and filtration which has been undergone by water entering the stream. In general, it would seem likely that stream water from watersheds with poorly drained soils will have penetrated less deeply into the soil than water from well-drained watersheds, and therefore, will have undergone less cleansing effect; but this may not always be true.

The significance of the soil score variable is probably due, to a considerable extent, to basic differences in geology between the watersheds in our sample characterized by well-drained soils and those characterized by poorly drained soils. Most of the variation in soils scores in our sample is due to differences between broad geographic areas; the watersheds with low average soil scores are all located in a well-defined region lying to the north of Philadelphia. Thus, the importance attributed to the soils score variable may be due partially to causal factors involving geology rather than to soil drainage itself.

Before discussing results for individual chemicals, it is worthwhile to consider briefly the data for the seven streams which were excluded from the sample. These data are presented in Table 9 below. As is shown by comparison with the means for the various chemicals given in Table 4, the concentrations for these seven streams tend to be very much higher than the concentrations in the sample actually analyzed; if left in the sample they clearly would have dominated the regression results. (Most values of R^2 would have been much higher if these streams had been included, since all the watersheds except stream 49 were very high in at least one of the indexes of urbanization.)

Table 9

CHEMICAL DATA FOR WATERSHEDS EXCLUDED FROM ANALYSIS

	Chemicals for which "Sewered in" is Significant											
	Fe	Ca	K	Na	HCO_3	Cl	NO_3	PO_4	SUM	ROE	$K\times10^6$	Ca, Mg
No population Sewered in:												
No: 49	.02	46	4.5	44	120	80	6.5	.10	363	336	601	181
90	.01	122	2.0	84	267	134	3.0	.79	763	812	1,230	440
Average:	.015	84	3.25	64	194	107	4.8	.45	563	574	916	311
Population Sewered in (Major disposal plants):												
46	.04	60	18.0	69	283	105	5.5	23.00	500	490	847	228
57	.08	69	20.0	126	128	181	75.0	2.20	718	755	1,190	267
58	.07	52	15.0	122	198	167	38.0	2.10	638	674	1,130	224
59	.07	54	12.0	89	207	115	34.0	2.70	532	557	910	213
67	.09	41	13.0	69	102	104	70.0	19.00	435	461	724	148
Average:	.07	55	15.6	95	184	134	44.5	9.80	565	587	960	216

	Chemicals for which "Sewered in" is not Significant						
	SiO_2	Mn	Mg	SO_4	F	Non-carb.	pH
No Population Sewered in:							
49	10	.00	16	76	1.0	83	8.4
90	27	.04	33	226	.4	221	7.9
Average:	19	.02	25	151	.7	152	
Population Sewered in (Major disposal plants):							
46	16	.04	19	67	.5	0	7.0
57	22	.11	23	138	.7	162	6.7
58	20	.25	23	103	.7	62	7.0
59	24	.00	19	83	.5	43	7.9
67	31	.09	11	45	.7	64	7.2
Average:	23	.10	19	87	.6	66	

It is of interest to consider these data simply to see if they are more or less consistent with the results obtained for the reduced sample. The most important feature of this set of streams is the presence of large amounts of population (and industry) which are "sewered in." Five of the seven watersheds contain major sewage disposal plants, each serving a far greater population than any disposal facilities in the watersheds left in the sample. For this reason, it is of particular interest to see whether the importance attributed to population sewered in seems to hold also for these streams.

In Table 9, the two streams without disposal plants and the five streams with disposal plants are segregated, and, for each group, separate means are computed for each of the 19 chemicals. The data pertaining to the 12 chemicals for which population sewered in has been found significant in the main analysis, with these streams omitted, are presented in the upper portion of the table; the data for the remaining chemicals are presented in the lower portion. It is noted that for the former set of chemicals, the mean for the five streams containing disposal plants is higher than the mean for the other two streams for 9 out of 12 chemicals. For the remaining chemicals (excluding pH), the mean for the streams with disposal plants exceeds the mean for the others in only 2 out of 6 cases. This provides a very rough indication that population sewered in is indeed more important for the first set of chemicals than for the second. Due to the considerable within-group variations the difference between means is statistically significant at the 5% level only for two chemicals, namely iron and potassium.

The fact that not all the relationships between means are as expected, and the fact that high levels of within-group variation are observed, presumably reflect the great differences in amounts of industry present in the various watersheds. The watershed of stream 90 (one of the two without disposal plants) contains a large amount of high water-polluting industry; on the other hand, the watershed of stream 46, which contains the largest sewered-in population, contains virtually no industry. Finally, it should be noted that for both nitrates and phosphates, the chemicals most prominently related to human activities, the means for streams with disposal plants are strikingly higher than the means for streams without disposal plants. However, these differences between means fail to be statistically significant because of high within-group variation.

Results for Individual Chemicals

With the results of the analysis as a whole in mind, we shall now consider the results for specific chemical indicators of water quality. In this section we will not attempt an exhaustive review of the results for each of the chemicals, but instead will concentrate our comments on the chemicals or groups of chemicals which are of greatest interest. The statistical results for each chemical are, of course, summarized in Tables 7 and 8.

Sodium, Chloride, and Potassium

Most of the urbanization-related variables were found to be statistically significant in explaining both the sodium and chloride concentrations. Only employment in high water-using and water-polluting industries failed to be significant for chloride; for sodium, population in post-war dwelling units sewered out was also not significant. The strong association with urban-related variables was somewhat expected for both of these chemicals.

Sodium and chloride tend to occur in similar concentrations, since they are most frequently derived from the single compound, sodium chloride. In solution sodium chloride tends to dissociate into sodium cations and chloride anions; in the soil, sodium cations can be absorbed onto colloidal surfaces and thus be removed temporarily from the soil-water solution, whereas the chloride anions tend to remain in the solution. Thus, one might expect sodium concentrations to be affected more by travel through the soils than chloride concentrations. In this regard, it is interesting to compare the four population-related variables considered here with respect to the probability that effluent must travel an appreciable distance through the soil to reach the stream. In the following table, the variables are arranged in increasing order of this probability (under the assumption that leakage from post-war sewer systems tends to be local whereas leakage from pre-war systems is more likely to involve the sewer mains running near the stream). It is notable that the ratio of the sodium regression coefficient to the chloride coefficient decreases with the probability

Table 10

COMPARISON OF REGRESSION COEFFICIENTS FOR
SODIUM AND CHLORIDE

Variable	Regression Coeffs.		Ratio of Coeff. Na/Cl
	Na	Cl	
Population sewered in	.01726	.02253	.766
Pre-war population sewered out	.00143	.00196	.730
Post-war population sewered out	----	.00230	----
Population unsewered	.00867	.02652	.330

that the effluent must travel an appreciable distance through the soil.

Potassium is an alkali metal, similar to sodium; however, it has a tendency to be selectively returned to the solid phase in the soil by recombination with clay minerals or by base exchange. As in the case of sodium and chloride, the soil score variable was found to be statistically significant in explaining potassium concentrations. This is consistent with the function of the soil of selectively removing potassium from solution. Of the urbanization variables, population sewered in and population in post-war dwelling units sewered out were found to be significant for potassium; population in pre-war dwelling units sewered out was also significant in the unforced regression. The failure of population in unsewered dwelling units to be significant may reflect the ability of the soil to remove potassium from sewage affluent within a short distance of travel.

As in the case of nitrate concentrations, potassium is much better explained by the urbanization variables in density form than in the forms used in the forced regression. The results obtained with all population-related variables in density form are shown below.

Table 11

REGRESSION FOR POTASSIUM WITH POPULATION-RELATED VARIABLES IN DENSITY FORM

Variable	Coefficient	t-statistic
Soil score	-.9370	3.74
Post-war sewered out	.0031	3.45
Pre-war sewered out	.0027	2.25
Sewered in	.0104	4.44

The value of R^2 for this regression was 0.53, as opposed to 0.43 in the forced regression.

Calcium, Magnesium and Hardness

All of the urbanization-related variables with the exception of employment in high water-using and water-polluting industries were statistically significant at the 1% level in explaining calcium concentrations. For magnesium, population sewered in and total manufacturing employment were not significant, and the overall level of explanation was somewhat lower ($R^2 = 0.60$, vs. $R^2 = 0.80$ for calcium). These results are generally consistent with the expectation that these chemicals might be related to human activities, both directly through their presence in industrial effluent and domestic sewage, and indirectly, through displacement by other cations such as sodium which are contained in sewage. The significance of the manufacturing variable for calcium was predictable since its presence in manufacturing effluent is common. Magnesium is not as commonly found in industrial effluents, so that the non-significance of the manufacturing variable might have been expected in this case.

The regression results for carbonate (or temporary) hardness are virtually identical to those obtained for calcium, with each regression coefficient roughly four times its value for calcium. This was to be expected since the two variables were almost perfectly correlated (R = 0.987).

For non-carbonate (permanent) hardness only two variables beside the soil score variable were significant, namely population in pre-war and post-war units sewered out. These results indicate that non-carbonate hardness does bear some relationship to overall intensity of urbanization.

Sulfates, Nitrates, and Phosphates

Sulfates, nitrates, and phosphates are among those constituents expected to be most influenced by man's activities. Somewhat paradoxically, in this study each of these chemicals has been found to be significantly related to relatively few of the independent variables which deal with man's activities. Only one of the independent variables, besides the soil score variable, was significant in explaining sulfate concentrations; two variables were significant for nitrates and two for phosphates (in forced form). The level of statistical explanation was high for phosphates but was quite low for nitrates and would have been low for sulfates without the soil score variable.

Sulfates, nitrates, and phosphates are all present in fully degraded sewage. However, sulfates and nitrates are derived from intermediate products of oxidation of sulfur and nitrogen, namely sulfides, sulfites, ammonia, and nitrites, which were not measured in this study. There may be a trade-off between amounts of nitrates and sulfates observed and the amounts of these intermediate products. This might explain partially why the concentrations of nitrates and sulfates alone are not correlated as highly with urbanization variables as we would expect for sulfur and nitrogen compounds on the whole.

Sulfates.

The strong contribution of the soil score variable in explaining sulfate concentrations would suggest that different soils vary greatly in their ability to filter sulfates. An alternative explanation would be that geologic factors are relatively more important as a source of sulfate than was anticipated. The appearance of population in pre-war sewered-out dwelling units as the sole urbanization-related explanatory variable for sulfates is difficult to explain. The failure of population in unsewered dwelling units to be significant might be explained by rapid filtering action of the soil, which would be most relevant to the effects of this population. The failure of population sewered in to be significant is surprising, although it is possible that the sulfur contained in the effluent from these disposal plants is concentrated in intermediate forms rather than in the stabilized sulfur form. With respect to population sewered out, it is likely that population in post-war as well as pre-war units is contributing to the the effect.

Nitrates.
Three urbanization-related independent variables were significant in explaining nitrate concentrations in the unforced regression. These three variables, all in density form, were: population in post-war dwelling units sewered out, population in dwelling units sewered in, and population in unsewered dwelling units (2,000-foot gradient). The last of these three variables was not significant when changed to mixed form in the forced regression. Nitrates was one of two chemicals, the other being potassium, for which the use of independent variables in density form was markedly more successful than the use of the forms chosen in the forced regression. The results of the regression with all the variables in density form are shown below; R^2 for this regression is 0.35 as opposed to 0.29 for the forced regression.

The failure of population in pre-war housing units sewered out to appear significantly is not considered particularly noteworthy.

Table 12

REGRESSION FOR NITRATES WITH POPULATION-RELATED VARIABLES IN DENSITY FORM

Variable	Coefficient	t-statistic
Post-war sewered out	.00248	5.06
Sewered in	.05854	3.87
Unsewered (2,000-foot gradient)	.02036	2.08

The significant features of the results obtained for nitrates were the greater success of variables in density form than in mixed or discharge form, and the failure of land in cultivation to appear as a significant variable. The latter finding was surprising because nitrate fertilizers are commonly considered to be a very important source of nitrates in surface waters. In examining these findings it was noted that nitrate concentrations seemed to have a positive relationship with stream discharge. Specifically, quite low values of NO_3 were observed for streams with very low discharge, even though these included some watersheds with very high percentages of land in cultivation. (The greater success of independent variables in density form, rather than a form involving discharge in the denominator, would also be consistent with there being some sort of positive effect associated with discharge.)

A further analysis of nitrate concentrations was conducted, using only the rural streams, with population densities below 250 people per square mile. This sub-sample was partitioned into two parts: the observations for thirteen streams to the north and east of Philadelphia, and 36 observations from the Brandywine area to the west of Philadelphia. For each of these groups taken separately, a "t-test" was performed to test for differences between nitrate concentrations where discharge was low. The dividing line between "high" discharge and "low" discharge was set at 0.2 cubic feet per second per square mile. (There were in fact no observations with discharge between 0.16 and 0.26 cubic feet per second per square mile.) In both cases, the means for observations with high and low discharge were found to be significantly different at the 1% level. These tests are summarized in Table 13.

These results would indicate that there is some sort of positive association between nitrate concentrations and discharge at base flow, at least for rural streams.

Table 13

COMPARISONS OF NITRATE CONCENTRATIONS IN HIGH AND LOW DISCHARGE WATERSHEDS

	Brandywine Observations		Observation N & E of Phila.	
	Number	Mean NO_3 (ppm)	Number	Mean NO_3 (ppm)
High Discharge watersheds	31	6.42	4	20.00
Low Discharge watersheds	5	2.58	9	4.54
Results of t-test	$t = 2.73$		$t = 4.99$	

Next, all of the observations with low discharge, including both Brandywine and non-Brandywine streams, were pooled together; and similarly for streams with high discharge. Within each of these groups of observations, the correlation between nitrate concentration and percent of watershed area in cultivation was computed. For both groups the correlation was positive, and for the high-discharge group it was highly significant ($R = 0.86$). The correlation for the low-discharge group ($R = 0.27$) was not statistically significant, but there was relatively little variance in nitrate concentrations in this sample.

Since the results for the high-discharge group were dominated by three non-Brandywine streams, with very high percentages of land in cultivation, the correlation was also computed for Brandywine streams alone. This correlation was 0.65, still statistically significant. Thus there did appear to be a strong positive relationship between nitrate concentration and the proportion of land in cultivation (which here may be a surrogate for intensity of cultivation as well as extensiveness of cultivation). This relationship was apparently obscurbed in the main analysis by the postive relationship existing between nitrate concentrations and discharge.

Although the study was eventually successful in demonstrating a relationship between nitrates and land in cultivation for a sub-sample of observations, the nitrate results on the whole were disappointing because of the low level of explanation achieved for the entire sample. This low level of explanation occurred because many of the highest nitrate concentrations pertained to streams in "urban fringe" areas, where the proportion of land in cultivation is fairly low but housing density is not yet high. The high concentrations observed for these streams remain a mystery; perhaps they are related to the presence of specialized types of agriculture (e.g., nurseries) which are often found in urban fringe areas.

Phosphates.

Phosphate concentrations in stream waters are known to be heavily affected by the presence of domestic waste, and in particular by household detergents. The results obtained are consistent with this; our results indicate that the determination of phosphate concentrations is attributed overwhelmingly to population in dwelling units sewered to disposal plants within the watershed. Since secondary sewage treatement does not remove phosphates from sewage effluent, municipal disposal plants simply serve as concentration points for the introduction of phosphates into streams. The failure of population in unsewered dwelling units to be an important influence on observed phosphate concentrations should perhaps have been expected, in view of the fact that phosphates introduced into the soil in small quantities are likely to be adsorbed onto soil particles or used as nutrients by plants. The failure of the manufacturing variables to be significant could perhaps also have been expected. On the other hand, the appearance of the pre-war sewered out variable but not the post-war variable probably has little significance in itself. As in the case of nitrates (where the opposite occurred), the situation is probably that populations in both pre-war and post-war dwelling units are contributing moderately to stream concentrations, with the effect of population in pre-war units being somewhat the greater.

As was mentioned earlier, the sample of observations for phosphates presented extreme problems of heteroscadasticity, i.e., dominance by large observations. For the original sample of 80 observations, phosphate concentrations ranged up to 19 and 23 parts per million (both for streams with major disposal plants), whereas for all but 9 of the observations concentrations were below 1 part per million. Even with 7 observations eliminated, as was done for all the chemicals, the remaining sample was overly dominated by a few observations. Therefore, an additional regression was run with all watersheds containing any population "sewered in" eliminated from the sample. The result was that the pre-war sewered out variable remained significant, and the soil-score variable also entered the regression (with a negative coefficient that was barely significant at the 5% level). R^2 was drastically reduced, from .90 to .40. It is notable that the mean phosphate concentration for this sample was only 0.14 ppm.

Consideration of the full set of data for phosphates suggests strongly that the coefficient value for the population-sewered-in variable given in Table 8, namely .00592, is somewhat too large. A regression of phosphate concentrations on population sewered in, using just the watersheds with non-zero values of the latter variable, yielded a coefficient estimate of .00300. An additional regression was also run using these observations, with both variables converted to logarithmic form in order to eliminate heteroscadasticity; the outcome of this was a coefficient estimate of .00269. Thus, it appears likely that a more accurate estimate of the coefficient relating phosphate concentrations to population sewered out is around .003 rather than .006.

Bicarbonate and pH.

The amount of bicarbonate present in a water body depends upon pH in the sense that bicarbonate is a dominant ion only in the range of pH from 4.5 to 8.2. However, since nearly all the streams in our sample had pH values well within this range, and since, in fact, there was little variation in pH, bicarbonate and pH levels were not highly correlated in this sample.

All of the urbanization variables were statistically significant in explaining bicarbonate concentrations, with the exception of population in post-war dwelling units sewered out. The omission of this variable probably has no causal significance. On the whole, a rather strong relationship of bicarbonate to urbanization is evident.

One of the unforced regressions for bicarbonates contained land in cultivation as a significant variable. These regression results are as follows (R^2 for this regression was .65):

Table 14

UNFORCED REGRESSION FOR BICARBONATES

Variable	Coefficient	t-statistic
Pre-war sewered out (mixed form)	.00738	6.36
Sewered in (mixed form)	.06495	3.84
Unsewered, gradient (mixed form)	.08669	5.83
Total manufacturing employment (density form)	.00830	2.39
Employment in high water-using and water-polluting industry (discharge form)	.13148	4.37
Land in cultivation (discharge form)	.86547	2.53

Only the soil score variable was significant in explaining pH. In this case, the soil score was probably serving as a surrogate for the chemical effects of geologic factors.

Manganese, Fluoride, Iron and Silica.
The levels of statistical explanation of manganese and fluoride concentrations were quite low. Only variables relating to manufacturing employment were significant. For fluoride, both total manufacturing employment and employment in high water-using and water-polluting industries were significant, whereas

for manganese only the total employment was significant.

Two variables relating to population, namely population sewered in and population in unsewered dwelling units, were signficant in explaining iron concentrations. The results indicate a general relationship with urbanization; but the choice of these two particular variables is not accorded a great deal of importance. In addition, total manufacturing employment was significant, as might have been expected.

The statistical explanation of silica concentrations was extremely low, with the only significant variable being population in unsewered dwelling units. No meaning is attached to these results, since silica is rarely found in domestic and municipal waste.

Total Dissolved Solids.

As discussed above, total dissolved solids was measured in three different ways: as the sum of individual components, as the residual on evaporation, and as conductivity. The statistical results obtained were very similar for the three cases, despite the fact that somewhat different samples were employed in each case. For all three measures of total dissolved solids, the following variables were significant: soil score, population in pre-war units sewered out, population sewered in, population in unsewered units, and total manufacturing employment. In addition, population in postwar dwelling units sewered out was significant for dissolved solids measured as residual on evaporation. Since total dissolved solids is a summary measure, the results are generally similar to those obtained for most individual chemicals. The strong effects of urbanization on this summary measure of water quality are evident.

CONCLUSIONS

Rather than summarizing all of the results presented above, we will present here several overall conclusions which have emerged from this study. First, significant effects involving urbanization have been found for a number of chemicals which are often considered as being geologically determined rather than produced primarily by human activities. Some of these chemicals are: calcium, carbonate hardness, magnesium, sodium, and bicarbonate. Second, the relative effects of urbanization variables upon chemical concentrations are quite similar for a large proportion of the chemicals. As was noted in the discussion of the results as a whole, there is a common pattern of regression coefficients (when significant), with large effects being attributed to population in unsewered dwelling units and to population in dwelling units whose sewage is disposed of within the watershed. Smaller effects are attributed to population in pre-war "sewered out" dwelling units, and still smaller effects to population in post-war dwelling units sewered out. Third, the small but nevertheless significant effects for population sewered out and for total manufacturing employment (most of which was in areas "sewered out") indicate that urbanization is likely to cause lower water quality regardless of what is done with sewage. The partial futility of sewage treatment is also demonstrated by the fact that regression coefficients for population sewered in are often as high as those for population in unsewered dwelling units. Fourth, although the importance of location of development within a watershed was not examined for sewered dwelling units, this location factor was found to be an important determinant of the effects of population in unsewered dwellings. Specifically, the effects produced were inversely related to distance from the stream channel. The results generally indicate that unsewered houses located 1/4 mile or more from the stream channel may have very little effect.

In general, the results indicate that urbanization has a pervasive influence on water quality.

IV. OPEN SPACE EFFECTS

INTRODUCTION

Almost by definition, urban development results in a reduction in the amount of land devoted to agriculture, forestry, and other natural uses. Generally, the only land left in open space uses is land which is set aside permanently as public parks, or is held in relatively open uses by institutions or by private owners. Some land is withheld from development by speculators who are waiting for the time when demand will justify high density development. Although their primary intention is not speculation, institutions and private house-owners also respond to development pressure, sell their land for more intensive redevelopment, and move on to newly developing areas elsewhere.

The loss of open space to development has serious consequences for stream hydrology and water quality, as detailed in the preceding sections. It also has consequences for the ecological health of the area and reduces the recreation opportunities and amenities available to residents.

A land use plan for water resources protection would maintain sizeable areas in open uses. However, it cannot be assumed that those areas would necessarily become fully developed in the absence of a plan. In fact, urban development in all but the most fully developed areas tends to be somewhat haphazard, resulting in "scatteration." Land near streams, in particular, tends to be either too wet or too steep to be prime building land. Therefore, in evaluating a land use plan for water resources protection, one must be careful to compare the amount of open space with the plan to the amount which would be expected without the plan.

RESEARCH PROCEDURE

In order to determine the probability that development would occur near a stream, we have examined a large sample of streams in the Pennsylvania suburbs of Philadelphia [Coughlin, Sheldon, & Hammer, 1971]. Heavily urbanized areas, such as

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the City of Philadelphia, were excluded from the sample since such heavy urban development is not likely to be typical in the future.

Most of the observations were made on air photographs (1" = 400') taken in the spring of 1970 for the Delaware Valley Regional Planning Commission. On these maps marks were made every 1000 feet along each stream and lines were drawn parallel to the stream at distances of 300 feet, 600 feet, and 900 feet. Each observation, then, referred to a segment 300 feet wide and roughly 1000 feet long. The final sample consisted of 1,926 observations: 856 segments lying within 300 feet of a stream, 606 segments lying between 301 and 600 feet, and 464 lying between 601 and 900 feet from a stream. The sample contained different numbers of segments in the three categories because only the closer segments were studied for many of the small streams.

For each segment the number of houses (that is, single-family and two-family houses) was counted, as was the number of apartment units. The amount of impervious area resulting from houses was estimated, and the amount of land covered by streets and by other impervious surface was measured. The size of the watershed at the location of each segment was noted and the average land slope (transverse to the stream) of each segment was measured from U.S. Geological Survey topographic maps. Finally, the 1970 population density of the township containing each segment was computed from Census data.

RESULTS

Percent of Segments Having No Development

The most extreme plans of land use control for water resources protection would prohibit all development near streams. For example, the Brandywine Plan proposed the public purchase of conservation easements which would prevent development in all flood plains and within 300 feet of all streams [Institute for Environmental Studies, et al., Section III-B p. 10-21]. The data collected in this study make it possible to determine to what extent such a development pattern has occurred "naturally" in suburban Philadelphia, in the absence of a conservation easement program.

Table 15

PERCENT OF SEGMENTS (0-300' BAND) HAVING NO DEVELOPMENT OF GIVEN TYPE, BY DENSITY OF TOWNSHIP

Type of Development	All Locations	Density of Township (persons per sq. mi.) 0-999	1,000-1999	2,000-2,999	3,000+
Houses	54.91	68.54	61.86	52.42	41.32
Apartments	97.31	100.00	98.31	95.42	98.20
Other impervious area	85.40	98.88	89.83	82.95	73.65
Streets	39.14	53.93	36.44	37.66	28.74
Total dwellings	53.04	68.54	61.02	49.11	40.12
Total impervious area	27.69	43.26	26.27	26.21	15.57

Of all segments within 300 feet of the stream, 53.04% were found to have no dwelling units at all (neither houses nor apartments), as can be seen in Table 15. In addition, 27.69% did not have any measurable impervious area: that is, no streets, dwellings, or other structures were observed. These would appear to be remarkably high percentages in view of the fact that no general programs have been carried out to preserve green space along streams in the Philadelphia region, and that streams with major valley parks (most of which are in the City of Philadelphia) have been omitted from the analysis.

As would be expected the percent of segements with no development falls as township density rises. The percent with no dwelling units falls from 68.54% in townships whose density is less than 1000 residents per square mile to 40.12% in townships whose density is 3000 or over. Similarly, the percent of segments with no impervious area falls from 43.26 to 15.57.

Percent of Segments Developed at Over 0.25 Dwelling Units Per Acre

A second development standard which has been suggested for water resources protection is the limitation of development to one house per four acres (or 0.25 dwelling units per acre). For example, in the Brandywine Plan [Institute for Environmental Studies, et al., Section III-B, pp. 21-24] this less stringent limit of 0.25 dwellings per acre was set for wooded areas and areas with slopes of 15% or more lying futher than 300 feet from streams and swales.

In our sample as a whole, only 53% of segments in the 301-600 foot band and 56% in the 601-900 foot band were more heavily developed than 0.25 dwellings per acre (Table 16). Intensity of development, however, increases with development density of township. Thus, in townships with overall densities between 3.0 and 5.0 dwelling units per acre, 87% of all segments in the 301-600 foot band and 100% of all segments in the 601-900 foot band are developed at more than 0.25 dwelling units per acre.

Not all the land within 301 and 900 feet of a stream would have the characteristics of "woods and slopes" and, therefore, not all would be placed under the restrictions approp-

Table 16

PERCENT OF SEGMENTS DEVELOPED AT GREATER DENSITY THAN 0.25 DWELLING UNITS PER ACRE

Township Density (du/ac)	Distance from Stream		
	0 - 300'	301 - 600'	601 - 900'
.001 - .250	5.66	15.79	18.19
.251 - .500	24.00	47.66	28.77
.501 - .999	27.96	45.87	50.47
1.000 - 1.999	43.68	55.69	58.98
2.000 - 5.000	50.32	77.96	88.38
All townships	37.50	52.81	55.80

riate to that land type. Therefore, under a Brandywine-type plan which limited development of woods and slopes areas to 0.25 dwelling units per acre, density of development in the 301-900 foot band would be greater than 0.25 dwelling units per acre. This fact makes the interpretation of Table 16 difficult, but it remains evident that development in suburban Philadelphia typically exceeds the densities envisioned in the 301-900 foot band by the Brandywine Plan.

Percent of Segments Developed at Over 1 Dwelling Unit Per Acre

It is instructive to examine one more density limit--one dwelling unit per acre. This is about the lowest density which can be maintained through zoning, since ordinances specifying a lower density are likely to be judged unconstitutional. It should be noted, however, that as a practical matter, one-acre zoning is not likely to withstand the pressures of development. As these pressures mount, rezoning can be expected which will enable development at higher densities.

Table 17 indicates that as long as the average density of dwelling units in a township remains below one dwelling unit per acre, the probability is rather small that land near streams will be developed at over one dwelling unit per acre. However, the farther a segment is from the stream, the greater its development is likely to be. For example, for townships in the density class of 2.0-5.0 dwelling units per acre, the probability is very great that development near streams will be greater than one dwelling unit per acre; it increases from 29% in the 0-300 foot band, to 64% in the 301-600 foot band, and to 77% in the 601-900 foot band.

Tables 15-17 give a rough indication of how development density of streamside segments varies with township density. However, it is not clear from the tables whether the variation in density is due solely to variation in township density, or whether it is related to other factors, such as valley slope, width of flood plain, or watershed areas. A simple cross-tabulation is not adequate for showing how the various factors interact in affecting density of development.

Factors Related to Density of Development

In order to take into account more than one variable at a

Table 17

PERCENT OF SEGMENTS HAVING ONE OR MORE DWELLING UNITS PER ACRE

	Distance from Stream		
Township Density (du/ac)	0 - 300'	301 - 600'	601 - 900'
.001 - .250	0	5.26	4.55
.251 - .500	6.40	30.22	15.07
.501 - .999	5.08	13.76	24.75
1.000 -1.999	24.57	35.77	41.75
2.000 -5.000	28.66	63.78	76.75
All townships	18.46	32.84	38.35

time in explaining density of development, a set of multiple regression analyses was performed. The dependent variable for each analysis was a specific measure of density of development of each segment. The independent variables consisted of density of township and a number of measures of each segment.

More specifically the dependent variables are:

Y_1	Density of Houses (du/acre)
Y_2	Density of Apartment Units (du/acre)
Y_3	Density of Streets (mi/sq mi)
Y_4	Density of "Other Impervious Area" (ac/sq mi)
Y_5	Density of Total Dwelling Units (du/acre)
Y_6	Density of Total Impervious Area (ac/sq mi)

These variables were computed separately for segments in the 0-300, 301-600, and 601-900 foot bands.

The independent variables used in all analysis are:

Z_1	Overall Valley Slope (within 900 feet from stream)
Z_2	Valley Slope in 0-300 foot band
Z_3	Valley slope in 301-600 foot band
Z_4	Valley slope in 601-900 foot band
Z_5	Width of Flood Plain (feet)
Z_6	Population Density of Township (persons/sq mi)
Z_7	Drainage Area of Watershed (sq mi)

Note that all variables except Z_5, Z_6 and Z_7 refer to the segments observed. Z_5 refers to the flood plain at the given segment, Z_6 to the entire township in which the segment is located, and Z_7 to the watershed of which it is the lowest point.

On the basis of logical considerations, one would expect that the independent variables act in combination, rather than singly. For example, a gentle valley slope should tend to encourage development, but this effect would only be important for areas (townships) with substantial overall densities; a gentle slope by itself is not enough to induce development. Therefore, a multiplicative regression model was employed. The form of the regressions was as follows:

$$Y_i = kZ_1^a Z_j^b Z_5^c Z_6^d Z_7^e$$

or $$Y_i = \log k + a \log Z_j + c \log Z_5 + d \log Z_6 + e \log Z_7$$

where Y_i is one of the dependent variables, $Y_1, \ldots, Y_6$, measured for one of the 3 distance intervals from the stream, and

where Z_j is the valley slope variable, Z_2, Z_3, or Z_4, pertaining to the given distance interval, and Z_1, Z_5, Z_6 and Z_7 are as defined above.

The results of the regression analysis are summarized in Table 18. Only significant variables are included, i.e., variables for which the t-statistics exceeded 2.0.

It will be noted that only three of the independent variables appear in the final regressions: overall valley slope, township population density, and drainage area. The more specific slope measurements for each band, and the variable expressing an approximate measurement of width of flood plain, did not prove to be statistically significant.

Population density of township, which appears in each equation, is by far the single best explanatory variable. This is consistent with the notion that urban development tends to engulf all in its path, without paying respect to natural features.

Overall valley slope appears significantly in six of the 18 equations, in four of the equations for the 0-300' band, and twice in equations for the 301-600' band. These results indicate that the greater the valley slope, the less development is likely. It is of interest that this relationship holds for houses, but does not hold for "other impervious area." This supports an impression experienced during data gathering: that single houses tend not to be built near

Table 18

SUMMARY OF REGRESSION RESULTS

	Dependent Variable[1]			Independent Variables Z_1 Log of Overall Valley Slope		Z_6 Log of Township Population Density		Z_7 Log of Drainage Area			
	Name	Band	R	Coeff.	t-Statistic	Coeff.	t-Statistic	Coeff.	t-Statistic	F Ratio	Level of Significance
Y_1	Log of Density of Houses	0-300'	.3150	-.0546	3.049	.1408	9.481	-.0438	6.300	46.4	1%
		301-600'	.3990	----		.2339	10.695			114.4	1%
		601-900'	.4062	----		.3076	9.327	.0583	3.316	45.5	1%
Y_2	Log of Density of Apartment Units	0-300'	.0783	----		.0386	2.280	----		5.2	5%
		301-600'	.1356	----		.0797	3.361	----		11.3	1%
		601-900'	.1759	----		.0740	2.828	.0409	2.949	7.3	1%
Y_3	Log of Density of Streets	0-300'	.2169	-.0606	2.529	.1029	5.186	-.0311	3.346	14.0	1%
		301-600'	.3625	-.0811	3.420	.1745	9.507	----		45.6	1%
		601-900'	.3515	----		.1988	8.000	.0281	2.121	32.4	1%
Y_4	Log of Density of Other Impervious Area	0-300'	.2510	----		.2336	7.569	----		57.3	1%
		301-600'	.2969	----		.3166	7.635	----		58.3	1%
		601-900'	.2175	----		.2624	4.785	----		22.9	1%
Y_5	Log of Density of Total Dwelling Units	0-300'	.3224	-.0702	2.720	.1838	8.532	-.0444	4.438	32.9	1%
		301-600'	.4007	----		.3058	10.747	----		115.5	1%
		601-900'	.4480	----		.3790	10.358	.0847	4.347	57.8	1%
Y_6	Log of Density of Total Impervious Area	0-300'	.3412	-.3824	4.628	.8056	9.586	-.1536	2.899	37.4	1%
		301-600'	.4452	-.3404	4.088	1.0957	12.163	.1290	2.112	49.6	1%
		601-900'	.4052	----	----	1.0556	9.526	----	----	90.75	1%

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[1] Multiple R's, Coefficients, F's and F ratios on last step of regression where all t's were greater than 4.0

[1] In order to avoid the problem of taking the logarithm of zero, arbitrary constants were added to the dependent variables before taking logarithms. Thus, dependent variables were constructed using constants from the set: 0.01, 0.1, 1.0, and 10.0. The resulting dependent variables which yielded the most significant statistical results are those to which the regression results of this table refer. Specifically, before taking logs, 1.0 was added to each of the above variables except density of streets, to which 10.0 was added.

streams, but that apartment houses and some non-residential uses often appear there. The implication is that in the course of development single houses are first built on the readily developable land; then as development continues, there is a market for higher intensity uses, and at the same time, relatively few readily developable sites remain. Streamside sites which in the earlier stage of development were uneconomical to develop, and which in some cases may have been protected by zoning, now can be developed economically for high density uses, and the zoning restrictions, which were adequate to withstand light and moderate development pressure, fall before the higher land prices created by the increased pressure for development.

The effect of drainage area is consistent, for the most part, with our impressions during data gathering: the larger the stream, the less likely is development within 300 feet of it. On the other hand, development in the 601-900 foot band is positively associated with size of watershed. It would appear that larger streams have a more obvious amenity value, which results from increased valley slope as well as increased size of stream. This amenity value is often protected by public or institutional land purchase, and is then capitalized on by private developers who build houses, apartments, and other structures as close to the protected (and physically difficult-to-build-on) area as they can get.

The regression equations for houses are summarized graphically in Figure 7. Since the effect of drainage area is significant for the 0-300 foot band, a separate curve is presented for drainage areas of .25, 2.5 and 25.0 square miles. The regression results for total impervious area are depicted in Figure 8.

In these curves, one can observe the rising development density of streamside segments with increased township population density, and the tendency of segments in outer bands to be more densely developed than segments nearer the stream, particularly for higher township densities.

CONCLUSIONS AND IMPLICATIONS

The general impression gained from the data is that stream valleys are relatively lightly developed. Remarkably high percentages of the segments studied have no development at

Figure 7

DENSITY OF DWELLING UNITS IN HOUSES FOUND IN BANDS ALONGSIDE STREAMS

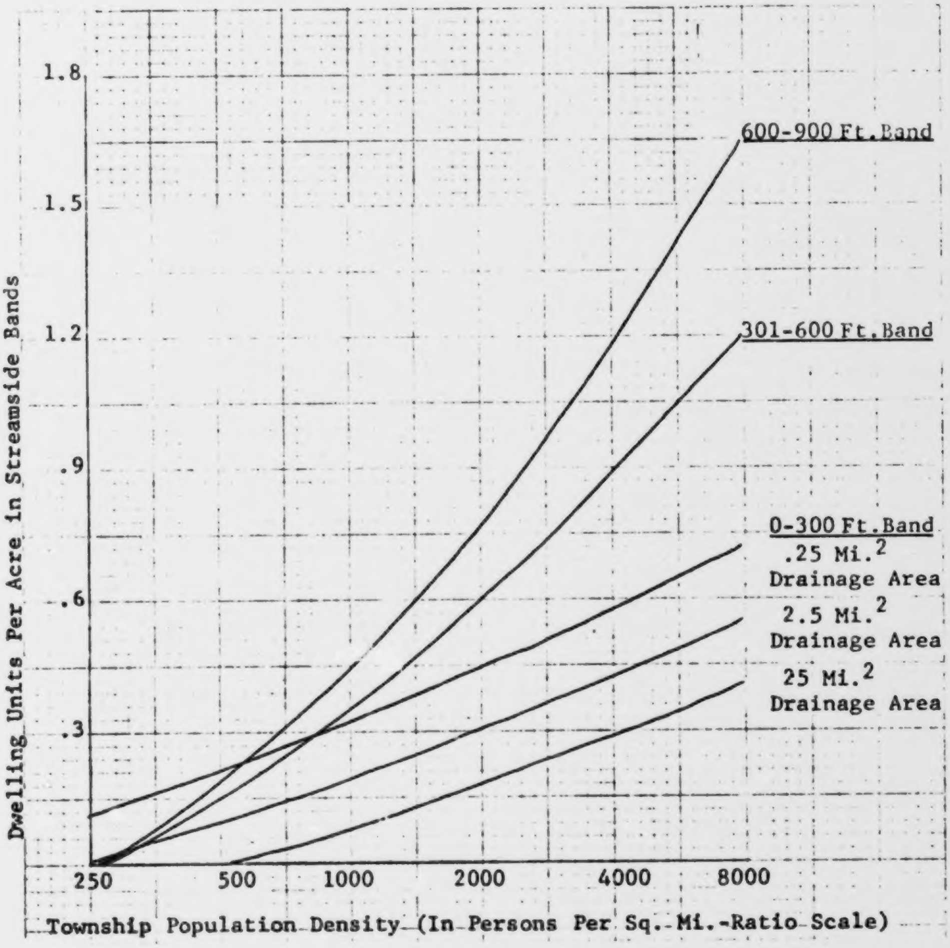
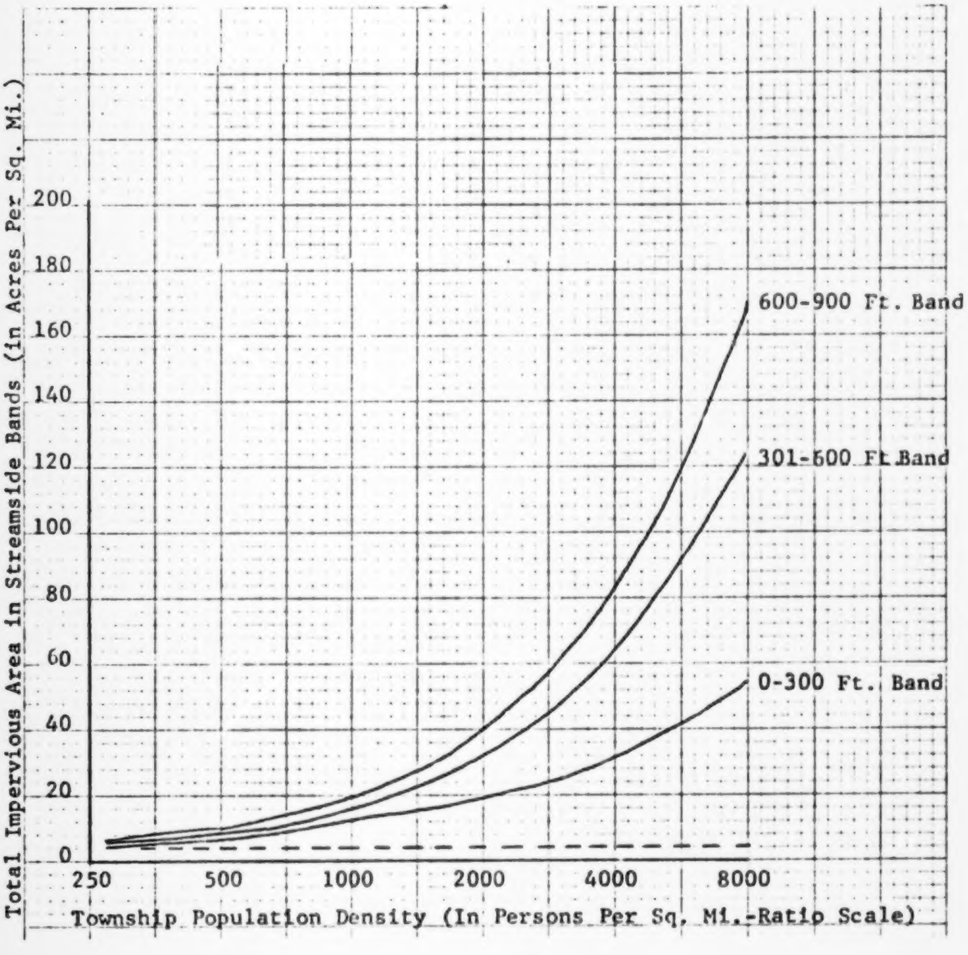


Figure 8

DENSITY OF TOTAL IMPERVIOUS AREA
FOUND IN BANDS ALONGSIDE STREAMS



all, except for streets. However, as township density rises, the amount of development in streamside segments increases also. Therefore, land use control programs are necessary if stream valleys are to be kept in an undeveloped state. Such programs are especially important if it is desired to retain a continuous green strip along streams, since even if natural market forces result in a small total amount of development, that development may change the visual impression of the landscape dramatically, and may interrupt streamside walkways.

The net effect of a land use control program depends upon two factors: the extent of development in streamside land when the program was put into effect, and the subsequent urban growth of the townships. An impression of the effect of these factors can be gained from examination of Figure 8. Assume that a control program which will prevent all future development in the 0-300 foot band is instituted at a time when total impervious area in the band is 4 acres per square mile. The amount of total impervious area in the band will not be expected to increase subsequently even though the population of the township grows substantially. This amount of expected impervious area is given by the dashed line in Figure 8. The net effect of the controls, then, is given by the difference between the dashed line and the curve showing expected amount of total impervious area in the 0-300 foot band under normal conditions. Thus, when township population density reaches 1,000 persons per square mile the net effect of the control program would be to have prevented the construction of 8 acres of impervious area per square mile--67% of what would normally have been built. By the time the township density had increased to 8,000 persons per square mile, the net effect would be to have prevented construction of 50 acres of impervious area--93% of what would normally have been built.

Alternatively, the same control program might not have been instituted until total impervious area in the band amounted to 12 acres per square mile. The net effect of such a program when the township reaches a density of 1,000 persons per acre would be estimated to be negligible, since on average a 0-300 foot streamside band in a township with a density of 1,000 persons per acre would have 12 acres of impervious area per square mile. By the time the township density had increased to 8,000 persons per square mile, however, the net effect of the program would be to have prevented construction of 42 acres of impervious surface per square mile. The prevention of so much impervious area would have strong effects on streamflow and channel enlargement.

It must be borne in mind that conclusions and implications drawn from the equations of Table 18 and the curves of Figures 7 and 8 should be treated as only rough indications of the amount of development which might be expected in any particular streamside segment. The data, however, are broadly representative of the Pennsylvania portion of metropolitan Philadelphia. It is believed that they would also be representative of rolling terrain in other metropolitan areas of the eastern United States.

V. EVALUATION OF EFFECTS: ASPECTS OF ENVIRONMENTAL PREFERENCE

INTRODUCTION

The previous three chapters have identified the major adverse effects of urbanization on hydrology, water quality, and open space. These consist of increased flooding, stream channel enlargement, deterioration of water quality, and reduction in the amount and continuity of open space. The objective of land-use planning for environmental protection is to minimize these adverse effects.

To determine whether a given plan is justified it is necessary to know not only the physical effects of the plan, but also the value of these effects to those who would benefit. Many of the benefits of the environmental effects do not have a market value. Instead, they consist of the personal enjoyment of the preserved environment received by individuals.

In order to determine the valuation which people place on environmental preferences, we must first consider some basic questions involving environmental preference. First, it is necessary to know whether persons tend to distinguish between environments and to form consistent preference orderings among environments. The second question has to do with whether different individuals tend to agree in their environmental preferences. In certain cases, it would appear obvious that people would have the same preferences for given environments: for example, one would expect persons to agree that an unpolluted stream is preferable to a severely polluted stream, all else being equal. However, it is not clear that substantial agreement can be expected in most environmental comparisons, since these typically do not involve extreme situations.

Third, given that there is substantial agreement among observers on environmental preferences, it is necessary to know the characteristics of an environment which elicit preferences. If we can identify the characteristics which determine preference, we can gain some understanding of how much a plan is going to effect things which are important to people's preferences.

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Since there is very little literature dealing with environmental preferences (see, for example, Craik [1968; 1969], Jacobs and Way [1968], Lansing and Marcus [1969], Michelson [1966], Peterson and Neumann [1969], Shafer, Hamilton, and Schmidt [1969]), it was necessary for us to undertake some relatively basic research in order to deal with the questions listed above. In the initial stages of research the focus was on the natural environment in general; in the later stages, it was possible to focus on stream sites and then on water pollution.

These investigations described in this chapter were in the form of pilot studies focused on differences between environments rather than on differences between judges. Therefore, no attempt was made to obtain observers who were fully representative of the entire population. In fact, in some of the investigations the observers were chosen to be representative of rather specific groups: of upper-middle-class housewives in one instance and of lower-middle-class housewives in another. Therefore, the results of these studies should not be ascribed to the population at large.

Preferences of middle-class housewives, at any rate, may be more relevant than preferences of the entire population to the evaluation of stream valley preservation plans. This point is discussed at greater length below, where it is noted that the persons who will receive the primary benefits of stream valley preservation are those who will move into the portions of the valley where development is allowed. These persons, given the current characteristics of the housing market, are likely to come from the middle class rather than, say, from the lower class.

AGREEMENT AMONG OBSERVERS ON ENVIRONMENTAL ATTRACTIVENESS

Before one can speak analytically about scenic benefits of conservation projects, one must have confidence that the public will show a substantial level of agreement on the attractiveness of a given scene. A corresponding question is whether the public will identify some scenes as substantially more attractive than others. In order to explore these fundamental questions, five pilot tests were conducted.

Table 19

DESCRIPTIONS OF THE TESTS

TEST	MAJOR OBJECTIVES	PROCEDURE	NUMBER OF JUDGES	PRE-TEST	ENVIRONMENTAL DISPLAY				RESPONSES
					NUMBER OF UNITS	TYPE	RANGE	METHOD OF PRESENTATION	
1. Environmental Abstraction Test	1. To determine whether judges can abstract the natural elements from a scene composed of both natural and man-made elements 2. To establish whether judges need specific instructions as to the definition of the natural environment	A. Rate attractiveness of each scene B. Rate attractiveness of the natural environment in each scene C. As B, but with more detailed and specific instructions	10	yes	20 slides	slides[1]	rural-urban	hand-viewer	ratings
2. Locational Character: Field Test	1. To determine extent to which field observers agree in rating locations for attractiveness	Rate the attractiveness of the natural environment in the field	2	no	92 locations	actual environments	rural-urban	field trip	ratings and short written comments
3. Locational Character: Photo Test	1. To gather evidence on consistency of field ratings and photo ratings 2. To determine whether a group of photographs can represent one location, and if one of those photos represents its group	Rate the attractiveness of the natural environment as seen in each slide	11	no	337 slides	slides	rural-urban	projection	ratings
4. Use and Attractiveness Test	1. To determine whether judges rate locations differently for residential use and for scenic enjoyment	A. (Assuming that each environment has the same services available to it) Rate each slide as to 1) desirability for living 2) desirability for driving through (or by) B. Rate desirability for living. On the first 25, give short explanation of response	10	yes	48 slides	slides	rural	projection	ratings
5. Consistency Test	1. To ascertain if responses change significantly after in-depth analysis of the slides by the judges 2. To determine whether judges are consistent in their responses after a time-lapse	A. Rate attractiveness of each slide B. Rate attractiveness of each slide after verbal analysis C. Rate attractiveness of each slide after wait of one month	11 11 7	yes	14 slides	slides	rural	hand-viewer	ratings (and oral comments between Phases A and B)

---

[1] 35 mm color transparancies

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Research Procedure

The objectives, procedures and other characteristics of each of the five tests are outlined in Table 19. Basically, the tests consisted of asking a number of judges to rate the attractiveness of a number of environments on a scale ranging from 1 to 7. In all but one test, which was conducted in the field, the environments were depicted by color photographs. With the exception of the first test, which included some midwestern scenes, all of the environmental displays consisted solely of scenes depicting the watersheds of the Upper East Branch of Brandywine Creek in Chester County, and the North Branch of Neshaminy Creek in Bucks County, Pennsylvania.

The major findings of the tests are summarized below. A full report on the tests has been published elsewhere [Coughlin and Goldstein, 1970].

Findings Concerning Agreement

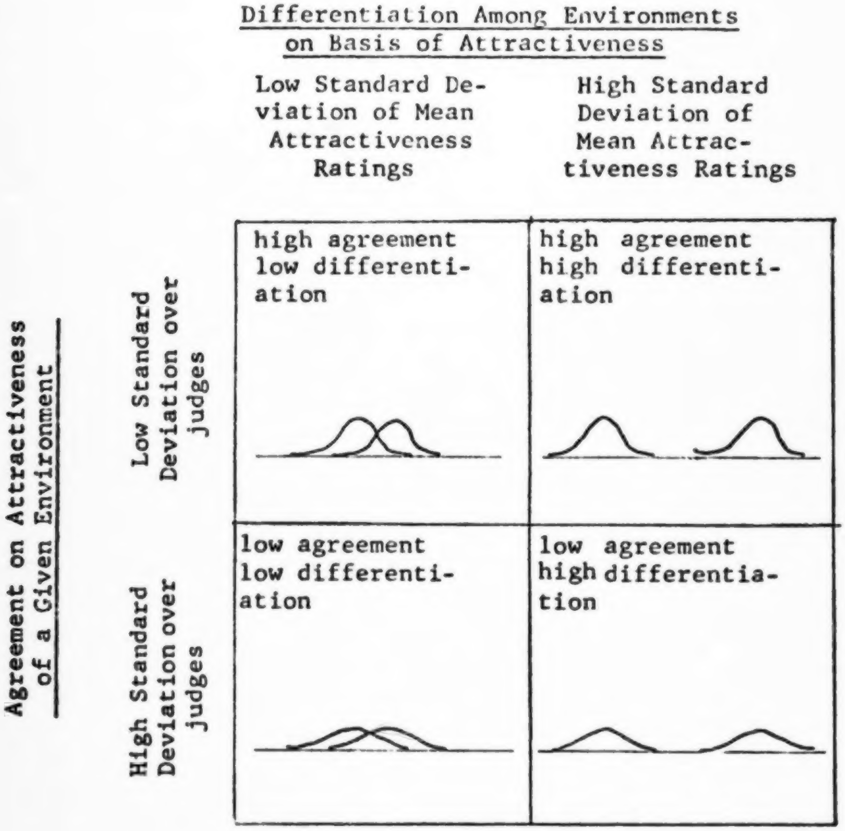
Differentiation among environments on the basis of preference or attractiveness rating requires (1) that judges tend to agree in the ratings they assign to a given slide, and (2) that mean ratings differ significantly among slides. A rough measure of the first property is the standard deviation of ratings by individual judges on a given slide. The smaller the standard deviation, the higher the level of agreement on a given environment. The second property is indicated by the distribution of mean ratings for each slide. The standard deviation of mean ratings provides one measure of this distribution: the larger the standard deviation, the more "spread out" or differentiated are the environments with regard to their perceived attractiveness.

As can be seen in Figure 9, various combinations of agreement and differentiation are possible. This diagram, of course, is equivalent to the concept of an analysis of variance, which deals with "within-slide" variance (difference in ratings by different judges on a given slide) and "between-slide" variance (difference in mean ratings).

Analyses of variance of the ratings given in the five tests indicate that judges are able to discriminate among environments on the basis of their attractiveness and tend to have a relatively high level of agreement on a given environment. In seven out of ten test situations, differences in the

Figure 9

THE CONCEPTS OF AGREEMENT AND DIFFERENTIATION


Differentiation Among Environments on Basis of Attractiveness
Low Standard Deviation of Mean Attractiveness Ratings
High Standard Deviation of Mean Attractiveness Ratings
Agreement on Attractiveness of a Given Environment
Low Standard Deviation over judges
High Standard Deviation over judges
high agreement low differentiation
high agreement high differentiation
low agreement low differentiation
low agreement high differentiation

Note: Each distribution refers to the distribution of attractiveness ratings by a number of judges on a given environment.

Table 20

PERCENT OF TOTAL VARIANCE IN ATTRACTIVENESS ACCOUNTED FOR BY PHOTOGRAPHIC SLIDES
(Results of One-Way Analyses of Variance)

	Number of:			
	Slides (Treatment Groups)	Judges	Percent Variance accounted for by slides	Significance level for rejection of hypothesis of no difference in mean ratings
1. Environmental Abstraction Test				
A. Entire Environment	20	10	51.2%	$p < 0.001$
B. Natural Environment only	20	10	69.5%	$p < 0.001$
C. Natural Environment given specific definition	20	10	69.2%	$p < 0.001$
2. Locational Character: Field Test[1]				
3. Locational Character: Photo Test	337	11	53.6%	$p < 0.001$
4. Use & Attractiveness Test				
A-1 Desirability for Residence	48	10	35.9%	$p < 0.001$
A-2 Desirability for sightseeing	48	10	35.3%	$p < 0.001$
B Desirability for Residence	50	10	35.2%	$p < 0.001$
5. Consistency Test				
A. Before commentary	14	11	51.3%	$p < 0.001$
B. After commentary	14	11	51.1%	$p < 0.001$
C. One month later	14	7	53.3%	$p < 0.001$

[1] An analysis of variance was not performed on the field test because there were only 2 judges. However other measures of agreement were found between the judges, and are reported in the section on this test.

slides themselves accounted for over 50% of the variance (Table 20) as determined by analysis of variance tests. The remainder of the variance is, by definition, accounted for by inter-judge differences in ratings on individual slides and by unexplained random variation.

The conclusion that there is a substantial level of agreement among judges on environmental attractiveness is impressive, considering the fact that the slides were relatively similar, consisting of typical scenes from suburban and rural areas near Philadelphia. No extremes of beauty or ugliness were included, at least as these would be judged by the researchers.

Consistency of Ratings

A preference rating is a subjective measurement and therefore cannot be replicated by asking any other observer to view the landscape under the same conditions and with the same instruments used by the initial observer. However, if preference ratings have any meaning it is necessary that there be no significant difference between the ratings given to a particular landscape by an individual on repeated observations. Similarly, mean ratings given by a group of judges should not vary significantly on repeated observations. It was found in Test 5 (Consistency Test) that mean ratings were not affected significantly by either an intervening in-depth analysis or a time lapse of one month. However, after the in-depth analysis, the judges tended to disagree with each other somewhat more than at the time of their first observation.

In summary, analysis of the five preliminary tests indicates that enough agreement among judges can be expected on the environmental attractiveness of landscapes for the use of average ratings to make sense.

LANDSCAPE CHARACTERISTICS RELEVANT TO PREFERENCES

Given evidence of significant levels of agreement among observers as to the attractiveness of different landscapes, it is possible to proceed to the second stage of the analysis: the identification of specific objective characteristics of those landscapes which could be shown to have significant relationship to preference ratings. This type of identification is highly important in any attempt to measure the important non-fiscal benefits of a proposed conservation project [Stevens and Coughlin, 1966].

Research Procedure

The data used in this stage of the analysis consisted of the 337 slides used in Test 3 (Locational Character--Photo Test), brief written comments by observers on the 14 of those slides which were used in Test 5 (Consistency Test), and other data obtained in the field as part of a much more extensive project (Field Test--Stream Sites). The Field Test involved 15 stream sites in the Philadelphia area, ranging in character from rural to completely urbanized. Data on water quality, channel enlargement, and other characteristics of streams which are related to urbanization of the watershed area had already been collected for most of these sites [Kawashima, Hammer, and Coughlin, 1970]; further information was gathered on 183 other variables, primarily measures of visual characteristics such as size and shape of the stream bed, roughness of surrounding topography, area covered by trees, grass, or other ground cover, and elements of visual pollution such as junk or discoloration of the water. Ten observers were then taken to these sites, and asked for brief written descriptions, as well as ratings of the sites on a 1-5 basis for 29 different preference scales. These observers were selected for their similarity in background and education, rather than for their diversity or "representativeness"; the rationale being that in this exploratory study the researchers wished to focus upon differences between sites rather than differences between observers.

Several different methods of analysis were employed. For the 337 slides of Test 3, extreme high and extreme low-scoring groups in terms of preference were selected, dominant characteristics of slides in each group were identified by inspection, and the extreme groups were then compared with each other and with the "average" group.

For the 15 photographs used in Test 5, the method was basically the same, but the analysis was much more thorough. For each photograph, a 17 x 23 descriptive matrix was completed, dealing with such aesthetic characteristics as Variety, Color, Brightness,Spaciousness, and Naturalness, applied to individual elements of the scene as well as to the whole. All of these characteristics were measured on a 1-5 scale. Three RSRI employees participated, each completing a matrix for each of the photographs; the results were then averaged for each photograph, and analyzed to determine similarities and differences between the five highest-scoring, the five lowest-scoring, and the "average" photographs.

For the Field Test data, a matrix of simple correlations (241 x 241) was produced, containing the 183 "objective" variables as well as means and standard deviations of the 29 preference scales for each stream.

Finally, the brief comments of the observers on the 14 photographs of Test 5 (Consistency Test), and the longer "objective descriptions" of 15 sites, which were provided by the 10 observers in the Field Test, were analyzed in terms of the frequency of occurrence of certain descriptive elements, and the evaluative connotations of these elements.

Findings Concerning Landscape in General

In general, the results of all stages of this analysis suggest that there does exist a reasonabley strong, consistent pattern of preference, with high agreement among judges as to the essentials of a "good" landscape. The findings for the photographic tests agree substantially with those for the Field Test. A brief summary of major conclusions follows.

1. There are some landscapes which everyone agrees are good.
    a. Preference and Agreement - For all tests, the correlations between mean preference scores and standard deviations, the latter of which measure the amount of disagreement on preference scores for any given landscape, are negative. This suggests that people tend to agree more about what they like than about what they dislike. These correlations are in no case significant, however; the highest is -.488 for Field Test Question 3, "How would you like to use this area for recreation?" (With this number of observations, a correlation would have to reach .52 to be significant at the .05 level of probability.

    b. Preference and Objective Content - When the 337 photographs from Test 3 (Locational Character - Photo Test) were analyzed as to objective content and dominant characteristics, the most highly preferred 10% of photographs were found to be strikingly similar. This similarity was even more pronounced for the sample of 14 photographs which were analyzed extensively as part of Test 5 (Consistency Test). Furthermore, 3 of the 6 highest-scoring Field Test sites contained the same general type of landscape which predominated among the highest-scoring photographs. For all three tests, the lowest-scoring landscapes were less similar, and those scoring in the middle range least similar of all.

2. These generally preferred landscapes have a strong tendency to be "parklike" or obviously man-influenced. Mowed grass and scattered large shade trees seem to be the determining factors. Judges may say, "This is nice because it looks natural, away from civilization." However, the scenes to which they are referring are not in a wild or natural state but are clearly "landscaped."

3. This preference for parklike landscapes is partially explained by the fact that, when the instructions on a test do not differentiate between preferences for "use" and for "abstract attractiveness" of sites, judges, in rating those sites, seem to think primarily in terms of their usefulness for recreation. "Recreation," moreover, seems to be defined primarily as "picnics," and only secondarily as "hiking" or "active sports."

The participating judges were able to discriminate between sites on the basis of active use to a greater extent than on the basis of scenic value. Thus, in the Field Test, there is considerably less variation among stream sites in the answers to the question, "How would you rate this site as a place to pass through and enjoy the scenery?" than in answers to questions concerning use of sites for living and recreation.

4. There are significant "minority preferences," relating primarily to extreme spaciousness, extreme seclusion, and extreme naturalness. These characteristics inspire strong emotional reactions among a few of the judges, and landscapes containing them tend to have disproportionately high standard deviations. This finding holds true over all aspects of the tests.

5. The characteristics common to those landscapes with high mean preference ratings and low standard deviations are largely synthetic, having to do with patterns and arrangements rather than with individual elements. Dislike, on the other hand, seems to focus on individual elements, and primarily on man-made ones. Certain types of man-made objects or conditions provoke an almost universal, strongly negative reaction: the tendency for low-scoring stream sites to show high disagreement among preference ratings is contradicted in the case of sites which show excessively polluted water, excessive amounts of trash, or excessively loud automobile noise. For such sites, ratings are uniformly low.

6. Elements mentioned as important by judges on high- and low-scoring photographs and stream sites tend to be the same as those which objective analysis shows to be strikingly different between the two groups. The preference for "parklike" landscapes is seldom explicitly verbalized,but in other respects, the things the judges say they like or dislike are, as far as we can tell, much the same as those to which they are reacting. The exception is the high proportion of the Field Test comments which were devoted to non-visual stimuli such as stream noise and grass smells: almost no significant correlations were found between preference ratings and pleasant non-visual characteristics.

Findings Concerning Stream Sites

The details of the Field Test, which was concerned with the evaluation in the field of a sample of stream sites, is of particular interest. Therefore, we will present its results in some detail.

The major significant correlations between the variables expressing objective characteristics of the streams and their settings and the 29 rating scales which express the preferences of the field observers are summarized in Table 21. Scales 1 through 12 and scale 17 represent answers to questions of the form "How much would you like to use this area for __________?" Responses were on a 5-point scale ranging from dislike very much (1) to like very much (5). The semantic differential scales (13 through 16 and 18 through 29) involve ratings, on a 1-5 scale, of the site on a continuum defined in terms of two opposite concepts. For example, in

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Table 21

SUMMARY OF MAJOR SIGNIFICANT CORRELATIONS BETWEEN OBJECTIVE CHARACTERISTICS OF STREAM SITES AND JUDGES' RATINGS - FIELD TEST

Variables Expressing Objective Characteristics:

Mean rating by judges for:	% Area Grass	% Foreground visible	"Open" banks	% Area buildings (midground & foreground)	Number of houses	Size of houses	Attractiveness of houses	% Area firm ground	% Area spongy ground	% Area twigs	% Area large junk	% Area small junk	Number medium rocks	Machine Noise	Weight-Berms	Area of frequent flooding	% View screened by vegetation	% Area "Exploited"	% Area "Natural"	% Area "Man-influenced"	Number of islands	Sand in stream	Plant smells	Placid stream	Rolling ground - foreground	Rolling ground - midground	Number of berms	High weeds	Length of view	Area of sandbars	% Area denuded ground	% Area flood debris	% Area trees	Speed of stream	Width of stream	Stream noise
Basic Preferences																																				
1. Living	●	◆	◆	◆	◆	◆				◎	-		-			-		-																		
2. Passing through		●						●	◎	-	◎	◎	◎	●	-											◆				-						
3. Recreation	●	●	●	●	●			◆	-	◎	●		◎		-	-	-	-				◆														
Recreational Preferences																																				
4. Wading										-	-	-			-																				-	
5. Walking	●	●	◆	●	●	●	●			◎	-		-	-	◎		-	-			◆	◆			-											
6. Picnicking	●	●	●	●	◆	◆		◆		◎	-		-	-	◎	-	-	●			◆	◆			-							-				
7. Camping	●	◆	◆	◆		◆	◆			◎		-	-		◎		◎			◆	●	●	●													
8. Playing ball	●	●	●	●	●	●	◆			-							●		-	◆	◆															
9. Meditating				◆	◆				-	-	-		-			-		-																		
10. Reading	●	◆		◆	●	◆			-	●	-		-			-										◆										
Semantic Differential Scales																																				
11. Visiting alone	◆								◎	◎	◎		●	-		●		-																		
12. Visiting with one other				◆				◆	●	◎	◎		-	-	-	-		-																		
13. Unattractive - Attractive		◆	◆	◆				●	◎	◎	◎	-	◎	-	-																					
14. Noxious - Healthy	●		●					●	◎	◎	◎	●	◎	-		●		●				●									-	-				
15. Barren - Lush	●		●																																	
16. Neglected - Well-kept	●		●	●	●	◆		●	-	◎	◎		◎	-		-																-				
17. Visiting with many others	●	●	●	●	●	●	◆			-					●		◎	-	-		◆	◆	◆			-										
18. Confining - Spacious	●	●	●	◆	◆	◆	◆			-							-	-	-			◆	◆	◆	-											
19. Closed - Open	●	◆	●	◆	◆	●	●	◆		◎			-			-	◎	-	-			◆		◆	-											
20. Dull - Picturesque		◆		●						-	-						●			●	◆					●	●		◆							
21. Low variety - high variety		●		◆											●					◆			◆													
22. Monotone of color - High contrast of color	◆		●					●		●		-			●		●			●	◆	●			-		●	●	◆	◆						
23. Interfered with - Natural								◆	●		●	●	●	-																	●	-				
24. Incongruous combination - Expected combinations								◆	●		●	●		-		-															●	-				
25. Separated pattern - Mixed pattern																						-											◆	●		◆
26. Ordered pattern - Random pattern	-		◎		◎	-	-			◆																						●	●	●		◆
27. Simple pattern - Complex pattern	-		◎			-	-			◆												-										●	◆	◆		
28. Pattern type						◎				◆							◆					-										◆	●		◆	
29. Exposed - Secluded						-	-			◆		◆	◆				●					-										●		●		◆

◆ or - Indicates correlation significant at .05 level; ● or ◎ indicates correlation significant at .01 level.

scale 14, a stream site which was judged noxious would receive a rating of (1), and a stream site which was judged healthy would receive a rating of (5). A "+" or a "-" in any column indicates a positive or negative correlation of .50 or higher (significant at the .05 level); a "⊕" or a "⊖" indicates a correlation of .62 or higher (significant at the .01 level).

Rows 11-29 in this table, containing three preference and 14 bipolar "semantic differential" scales, are given in five clusters, each of which shows extremely high correlation among its component scales. These clusters were derived from a linkage analysis of the inter-correlations among rating scales; they may be regarded as factors or dimensions relevant to preference. The three rating scales for "Visiting alone," "Visiting with one other," and "Visiting with many others" were included in these clusters because of their strikingly close relationship to specific semantic differential scales.

These clusters, although distinct, are not in the least independent of each other. Nearly every rating scale in the first four clusters is positively and significantly correlated at the .05 level with most of the other rating scales. The fifth cluster, composed of scales which seem to describe a wooded, secluded stream valley, is the only one which is not significantly related either to other semantic differential scales or to the basic preference scales (the first three scales in the table).

Inspection of the table shows a few objective characteristics with consistently significant relationships to preference. They are:

Positive: percent of area covered by mowed grass, percent of foreground visible, "open" banks, percent of foreground area that was firm ground, and, surprisingly, several variables denoting number and size of houses. These last correlations may have been due to a tendency for preferred sites to be in "high-status" rural areas, where open lawns and meadows provided views of the large houses of the owners.

Negative: all variables denoting presence of junk, percent of area covered by twigs, area of spongy ground, number of medium-sized rocks in and around streams, and height of berms (secondary banks). The last correlation is probably due to the extremely high berms of the two sites having large amounts of junk and trash. Unpleasant noise, though mentioned frequently in the comments, is important only for "passing through to enjoy the scenery," not for "living" or "recreation."

A striking feature of these important variables, especially those with positive correlations to preference, is that they seem to involve primarily characteristics which have been created or influenced by man, rather than "natural" features of the site. The preference for open, parklike areas, noted in the previous section, is quite evident here, and there is some indication that neighborhood status is also a factor. Some of the less significant negative correlations are related to relative degree of urbanization of the watershed, but it is difficult to tell if this is a reflection of the noxious influence of urbanization on the stream itself, or simply of the low status of the surrounding urban neighborhood.

Among the 183 variables tested there were several variables relating to characteristics of the stream whose relationships to urbanization have been studied in other parts of this project. These were channel enlargement and various aspects of water pollution. None of these variables had an appreciable number of significant correlations with either preference scales or the semantic differential scales. Thus, these variables are not included in Table 21. Indicative of the relative unimportance of these variables is the fact that the site most preferred of all was one in which the stream, which drained a highly urbanizaed area, had generally poor water quality and a greatly enlarged channel. (Its channel enlargement ratio exceeded 3.0.) The stream, however, ran through a well-kept park with large trees and grassy expanses.

One finding, which is not evident from inspection of Table 21, involves the dimensions of the area which is relevent to preference for a site. Since many characteristics were scored separately for banks, foreground, mid-ground, and far-ground, the highest correlation for a particular characteristic would indicate the most important location for that characteristic. For most variables, these important locations were foreground and mid-ground: in other words, their influence on preference does not extend beyond a distance of about 200 feet. For the major positive and negative factors, namely grass, large junk and twigs, only the banks and the foreground area showed significant correlations. Comments on the sites, however, indicate that the "atmosphere" of an area, including all of the visible and audible surroundings, is also an important factor.

Patterns of Preference

Some other very interesting patterns are evident in Table 21. Some of the concepts involved in preference, for instance, seem to be basically negative: The absence of certain detracting elements is what is important. Preference ratings for "Passing through to enjoy the scenery" and the first four scales of the first semantic cluster are the prime examples. The large majority of significant correlations between these scales and objective variables are negative correlations with variables which express unpleasant characteristics. Relatively few positive correlations exist with variables expressing positive characteristics. This indicates that the primary difference between a good site and a bad site for a typical observer is simply the presence of negative characteristics in the latter, rather than the requirement that a "good" site possess particular positive features. For "use" (recreational preferences) questions, on the other hand, and for all scales in the second cluster, both positive and negative characteristics are extremely important. This could be interpreted to mean that judges tend to be more demanding when rating the "use" aspects of a site; that is, judges require that certain positive features be present for a site to be good, in addition to requiring the absence of negative characteristics.

One possible explanation for this pattern is that persons are in a sense starved for naturalness, or the illusion of naturalness, so that nearly any stream site will be considered attractive as long as it lacks certain obviously detracting man-made characteristics. Another possible explanation could be that this group of judges has more uniform and well-articulated preference standards for use of sites than for "attractiveness" in the abstract.

The preceding paragraphs have related judges' ratings to objective characteristics of site. A different approach to the analysis of preference patterns is to relate the judges' preference ratings to their own judgments concerning the basic aspects of the site, as expressed in the semantic differential scales. Preference ratings of the sites as places for "living," places to "pass through" and to "enjoy the scenery," and as places to visit for "recreation" were most highly correlated with semantic differential scale ratings for "Attractive" and "Healthy"; preference ratings for "Living" and "Recreation" were also highly correlated with ratings for "Spacious," while preference ratings for "Passing through" were highly correlated with ratings for "Picturesque."

Although several psychological studies have demonstrated that both animals and humans of all ages show a preference for a complex over a simple stimulus pattern,and though our analysis of photographs has indicated that high variety is associated with high preference, the judges in the field experiment consistently preferred sites which they saw as "ordered" and "simple" in pattern. The correlations are seldom significant--the highest is .52 for the correlation between "ordered pattern" and preference rating of sites for "Living" and "Recreation"--but the signs are positive for correlations between all preference variables and "ordered," and negative for correlations between nearly all preference variables and "complex pattern" or "pattern type." This does not mean that the preferences of these field judges were different from those of the judges of photographs; judgments of "high variety" are still significantly associated with high preference ratings. Rather, it would seem to indicate that these judges--as well as the judges in the earlier test using photographs--have difficulty appreciating variety unless it is in some way logically or aesthetically ordered.

QUANTITATIVE MEASUREMENT OF LANDSCAPE QUALITY

Research Procedure

Based on the above findings, objective measures of "landscape quality" were defined. These measurements were applied to photographs of the Field Test sites, the results averaged over all photographs depicting a given site, and the resulting variables were entered in regression analysis with normalized mean preference ratings as the dependent variables. A full report from which the following summary was made can be found in Rabinowitz and Coughlin [1971].

The landscape quality variables are listed below.

1. Variety of Elements. Hypothesis: a high variety of elements in a photograph will be associated with high preference. Measure: number of different element categories in each photograph, element categories being defined in terms as simple and intuitively obvious as possible: trees, bushes, streams, mowed grass, high grass.

2. Variety of Brightness. Hypothesis: high variety of brightness will be associated with high preference. Measure: difference between the highest and lowest readings obtained by moving a photographic light meter back and forth over the projection on a viewing screen of each photograph.

3. Size of Largest Trees. Hypothesis: a large tree dominating the photograph will be associated with high preference. Measure: total area covered by largest tree in photograph. The area in the photograph with the highest measurement is used as the measurement of a group of photographs depicting a site.

4. Length of Longest View. Hypothesis: an unusually long view will be associated with high preference. Measure: logarithm of estimated distance of longest view, in feet. The measurement in the photograph with the longest measurement is taken as the measurement for a group of photographs depicting a site. The log scale emphasizes differences between relatively short distances, and correspondingly deemphasizes equal differences between longer distances.

5. Spaciousness-Seclusion. Hypothesis: observers prefer neither too much open space nor too little; a low score on spaciousness-seclusion will reflect the moderate degree of openness desired by subjects, and will, therefore, be associated with high preference. Measure: the absolute value of the difference between the figure for variable 7 (Actual Open Space) for a given site, and the mean of all measurements for variable 7 over all slides.

6. Misfits. Hypothesis: presence of misfits will be associated with low preference. Measure: total area of photograph covered by misfits. A "misfit" was defined as any man-made object neither insignificant nor obviously attractive.

7. Actual Open Space. Hypothesis: a large amount of open space will be associated with high preference. Measure: area of "open space" in photograph times measurement for X_4 (Length of Longest View). This measurement provides an index of the actual area of open space at the pictured site.

8. Area of Water in Photograph. Hypothesis: a large area of water in a photograph will be associated with high preference. Measure: area of water in each photograph, measured for all photographs for any site which showed any water at all, and then averaged. In order to approximate the actual amount of water present at the site, those slides which were taken looking away from the streams were eliminated from the calculations.

9. Area of Frequent Flooding. Hypothesis: a large area of frequent flooding will be associated with low preference. Measure: total area of sand or pebble bars or denuded ground within the stream banks in photograph.

10. Number of Visible Rocks. Hypothesis: a large number of rocks will be associated with low preference. Measure: number of rocks greater than one foot in diameter.

Several other "quality" characteristics were also measured for use in these equations, for instance: "Variety of Color" and "Presence of Water." The fact that all the highly preferred photographs in the Consistency Test showed open expanses of lawn with scattered shade trees suggested that total area of open space (defined as anything that can be walked on or through without difficulty), area of mowed grass, or arrangement of open space (unbroken space vs. space interrupted by bushes or trees) might also be important. But none of these measurements turned out to be significantly associated with preference ratings.

The 10 variables described above were measured for color slides (as viewed on the screen of a projector-viewer) of the stream sites which were the subject of On-Site Observations. Most of these slides were also used for a set of Home Interviews, in which 18 middle-class suburban housewives and mothers participated. Their social and economic characteristics were remarkably similar to those of the subjects in the On-Site Observations.

Findings

Table 22 gives the equations which were derived, using site ratings as the dependent variables and site characteristics measured from slides as the independent variables, for the On-Site Observations and the Home Interviews.

In the equations for the On-Site Observations, as in the equations for the Home Interviews, the independent variables were derived from the slides which were used in the Home Interviews--in other words, the two slides which together provided the best representation of each of the actual slides.

The set of equations for the On-Site Observations (Table 22) is quite interesting. We obviously cannot claim that the characteristics of the slides, which were chosen many months after the On-Site Observations had taken place, had any causal relationship to the ratings which subjects assigned to the sites themselves. Nevertheless, these equations, which were initially derived merely to provide a basis for comparison with the equations for the Home Interviews, show highly significant correlations between the ratings in the field and many of the slide characteristics.

It should be kept in mind that these multiple regression analyses all involve extremely low numbers of degrees of freedom. Although this fact is taken into account in the tests of significance, nevertheless, having this few degrees of freedom is highly undesirable. The reason for this is that the estimates are highly sensitive to values of variables for individual observations, so that a large error component in a single observation can have a major effect on the regression results. Thus, the results should be viewed with extreme caution. They are published in spite of these limitations, since the study is admittedly an exploratory one and because the levels of significance are unusually high.

Three variables appear as consistently significant in the equations for the On-Site Observations: X_2, Variety of Brightness, X_3, Size of Largest Tree, and X_8, Area of Water. (The negative sign on the correlations with X_2, Variety of Brightness, unfortunately runs counter to our earlier results, and to our hypothesis that high variety will be preferred.)

Table 22

REGRESSION EQUATIONS EXPLAINING PREFERENCE BY MEASUREMENTS OF LANDSCAPE QUALITY

Independent variables (measurements on photographs)	Dependent Variables (Ratings by Observers)											
	On-Site Observations (15 slide groups)						Home Interviews (14 slide groups)					
	Question A		Question B		Question C		Question A		Question B		Question C	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
X_1 Variety of Elements									-10.054	1.387	-7.290	1.553
X_2 Variety of Brightness	-1.355	.506	-1.774	.381	-2.518	.715	-.820	.155	-3.247	.377	-2.577	.467
X_3 Size of Largest Tree	.215	.075	.244	.051	.241	.069	.091	.018	.259	.034	.186	.041
X_4 Length of View					-15.511	6.367						
X_5 Spaciousness-Seclusion			-14.954	5.519			-7.583	2.145	-28.456	2.726	-21.474	3.137
X_6 Misfits			-4.400	.114			-.336	.030	-.475	.036	-.443	.042
X_7 Area of Open Space times Length of View					.040	.021	.028	.006	.024	.007		
X_8 Area of Water	.139	.063	.206	.042	.101	.053			.222	.026	.208	.029
X_9 Area of Frequent Flooding			.289	.117			-.646	.050	-.295	.049	-.353	.055
X_{10} Number of Rocks > 1 ft. in Diameter							.257	.042	.215	.052	.193	.059
R^2	.6035		.9108		.8216		.9884		.9906		.9781	
F Ratio	5.605		12.137		8.257		73.288		47.328		28.039	
Significance Level	$p < .01$		$p < .01$		$p < .01$		$p < .001$		$p < .001$		$p < .001$	

Note: Question A: How would you like to live here?
Question B: How would you rate this site as a place to pass through and enjoy the scenery?
Question C: How would you like to use this site for recreation?

The equations which were derived for the Home Interviews experiment (later columns of Table 22) are very similar to those for the On-Site Observations, with an even higher percentage of variance explained by the slide characteristics. In all three of these equations the multiple R^2s are .97 or higher, at an inordinately high level of significance. Furthermore, all but one of the "photo quality" variables are significantly related to preference ratings in at least two of these equations; and only three of these relationships are significant at a lower significance level than .02.

According to our original hypotheses, X_2, Variety of Brightness and X_4, Length of Longest View, would be expected to show positive correlations with preference ratings. However, they appear in Table 22 as negatively related to preference. This suggests that, if the Home Interviews method did indeed emphasize the "real world" aspects of the sites rather than the aesthetic qualities of the slides, then subjects in a "real world" situation evidently prefer a fairly secluded site (short length of view), but not one which is heavily wooded (heavily wooded sites scored highest on X_2).

For both the On-Site Observations and the Home Interviews, the negative correlation coefficient for "Variety of Brightness" is lowest in the equation for Question A--"How would you like to live here?"--an indication that the seclusion provided by thick woods has some positive value in a residential situation.

The characteristics of the desired landscape are further illuminated by the large, and highly significant, negative correlation for X_5, Spaciousness-Seclusion, which appears in the majority of the equations in Table 22. The high significance of this correlation provides added support for the hypothesis that the "generally preferred" type of site conforms to a fairly precise degree of spaciousness, neither too open nor too confining.

It will also be noted that in both sets of equations the level of explanation for Question B, "How would you rate this site as a place to pass through and enjoy the scenery?" is higher than for either of the others, and that the Home Interview ratings were most highly correlated with the On-Site Observation ratings for this question. It would seem that the cultural stereotype of the "attractive landscape" for scenic enjoyment is more clearly defined, and more closely agreed upon, than the conception of a landscape that is useful or liveable.

Most of the other correlations which appear in Table 22 are as expected. There is a positive correlation for X_3, Size of Largest Tree, and there are small positive correlations for X_7, Area of Open Space times Length of View, and X_8, Area of Water. Negative correlations for X_9, Area of Frequent Flooding, in the equations for the Home Interviews, suggest that some of the effects of urbanization on a stream may be perceived as deleterious. The large negative correlation for X_1, Variety of Elements, in two of these equations (contrary to the direction of correlation expected), suggests the hypothesis that visual complexity high enough to result in visual confusion would be disliked. However, it is doubtful that any of the sites were complex enough to account for such a response.

These equations cannot be interpreted as a "model" of preference patterns, which could be used to predict preferences of different subjects for different landscapes. Our samples of both subjects and landscapes have as yet been far too small. But the general consistency of these measurements in explaining these sets of preference ratings convinces us that we have succeeded in uncovering certain very important aspects of landscape quality.

THE INFLUENCE OF WATER QUALITY IN THE EVALUATION OF STREAM SITES

The previous sections have indicated that individuals do appear to prefer some natural environments over others, and to be reasonably consistent in their preferences. A substantial level of agreement among individuals has also been observed. Preferences were found to be related to a number of environmental characteristics. Subjects tended to respond negatively to obvious noxious human influences such as junk, but tended to prefer parklike scenes to more natural landscapes. Most of the environments studied, either in the field or by photograph, consisted of stream sites; however, the preferences expressed for these sites do not appear to have been dominated by reactions to the stream itself. Therefore, a series of studies was conducted which focused on how stream preferences are influenced by water quality.

Research Procedure

In the first of these studies, the Pollution Perception Study [Scherer and Coughlin, 1971], which is summarized in this section, a number of subjects were taken to observe a dozen stream sites. The other studies, which are reported in the next chapter, involved household surveys in which subjects were asked questions about the stream nearest their residence.

Unlike the Field Test reported in the previous section, the subjects in the Pollution Perception Study were asked a number of questions relating specifically to the condition of the stream, the surrounding area, and the area as a whole. Questions concerning pollution were mixed in with other environmental questions so that the respondents would not realize that the main focus of the study was water pollution, and, therefore, accord pollution excessive importance in their answers in order, perhaps subconsciously, to please the researchers. The respondents' answers were analyzed in relation to a wide variety of other objective measures of stream condition.

The general procedure followed in the Pollution Perception Study was as follows: Twelve stream sites were selected which were as similar as possible physically, but which varied in water quality. Twelve observers, lower-middle-class housewives for the most part, were taken to these sites over a period of two consecutive days, Each filled out a questionnaire on each site, with respect to the area within about 100 feet from the observation spot. While the respondents filled out their questionnaires, two investigators rated the stream on a number of attributes referring to physical characteristics and water quality. In addition, water quality samples were taken for all the streams within an hour of each stream site interview.

Laboratory Analysis was performed for the following chemicals:

Chemical Oxygen Demand (COD)
Total Coliforms
Fecal Strep
Total Phosphates
Ortho Phosphates
Organic Nitrogen
Total Dissolved Solids at 103°C
Water Temperature
Acidity-Alkalinity (pH)

Organic Nitrogen
Ammonium Nitrates
Nitrites
Nitrates
Sulfates
Chlorides
Total Dissolved Solids at 179°C
Dissolved Oxygen

Using the resulting data, the streams were grouped roughtly by level of organic load, as shown in Table 23. An overall Water Quality Index was also calculated for each of the 12 streams using the methodology of Brown, McClelland, Deininger, and Tozer (see Chapter VI, p. 171, for a description of this method). Since data were available on only seven out of the nine variables used by Brown et al., the indices were computed on the basis of the seven variables, which allow a possible high score of 80, for best water quality and were then expanded to a scale with a possible high score of 100.

The range of water quality as shown by the Water Quality Index was 20.5 to 63.5 on a possible scale of 0-100. Although the range was rather wide, none of the streams could be described as having unusually good water quality. Also, dramatic evidence of pollution, such as severe discoloration or accumulations of foam or scum, was not present.

Subjects were asked to answer the following three basic questions on a scale of 1 (dislike) to 5 (like): "How much do you like the area within about 100 feet which you can see from this spot?", "How much do you like the stream itself?", and "How much do you like the surrounding area?"

Two other important sets of questions were asked: The first set concerned how much the respondent would like to engage in each of a number of activities at the site. The second set concerned the subjects' perceptions of the site; these asked the respondent to state the extent to which the site could be described by terms such as "pleasant," "healthful," "inviting." A number of the questions concerning perception related specifically to the conditions of the water; that is, is the stream rapidly flowing, transparent, clean, smelly, pleasant, full of trash, inviting color, polluted, healthy?

Findings

The responses to questions involving perception of stream conditions indicated that people are able to identify water pollution reasonably well. Table 24 gives the statistically significant correlations between perceived water attributes and various chemical and biological measurements of water quality. The greatest number of significant correlations occur for the following four perceived attributes: transparent,

TABLE 23

STREAMS GROUPED ACCORDING TO LEVEL OF ORGANIC LOAD

	1	2	3	4
	Heavy Organic Load	Moderate Organic Load	Low Organic Load	Very Low Organic Load
	Streams 6, 8, 12	Streams 7, 9, 10	Streams 3, 4, 11	Streams 1, 2, 5
Measures of Organic Load				
Total P (ppm)	15.20 - 23.60	.47 - 12.20	.18 - 1.88	.07 - .24
Ortho P (ppm)	19.40 - 28.00	.43 - 13.20	.09 - 2.08	.00 - .06
NO_2 (ppm)	.74 - 1.76	.16 - 2.67	.04 - .07	.02 - .05
NO_3 (ppm)	25.72 - 33.33	11.00 - 21.20	5.15 - 6.08	1.72 - 13.96
Measures of Sewage-Related Pollution				
Total Coliforms	1270 - 4000	4000 - 24000	3000 - 9500	1000 - 1825
fecal strep	100 - 275	70 - 95	240 - 1645	340 - 1070
TDS 103^{o} (ppm)	434 - 520	418 - 567	118 - 274	75 - 123
TDS 179^{o} (ppm)	342 - 508	342 - 522	75 - 208	43 - 88
W.Q.I.	20.5 - 29.0	37.9 - 46.6	48.3 - 59.5	48.0 - 63.5

clean, polluted, and healthy. Most of the significant correlations involve the following chemical characteristics: COD, Fecal Strep, Total Phosphates, Ortho Phosphates, Nitrates, Chloride, Total Dissolved Solids, and the Water Quality Index. Most of the correlations show the expected signs.

However, four desirable attributes are positively correlated with fecal streptococci; this apparently spurious result occurred because the concentration of fecal strep was high for rural streams where water quality was generally good. The negative correlations between various chemical measurements and the "rapidly flowing" attribute are probably spurious also since there is no logical relationship between water quality and speed of flow. This result could be due to particular characteristics of the sample of streams, that is, the polluted streams happened to be slow-flowing. It is notable that the highest correlation observed is the correlation of -.72 between the perceived attribute "polluted" and the overall Water Quality Index.

The perceived water attributes were also significantly correlated with a number of objective, but non-chemical, characteristics of the stream (see Table 25). The highest correlation involved the percent of the stream bed covered with mud. These correlations reflect a dislike of mud on the part of the subjects plus the fact that other stream characteristics such as speed of the flow of the stream tend to be associated positively or negatively with the existence of a muddy stream bed. Of the seven objective characteristics of the stream which might be related to water quality--algae, rooted aquatics, floating solids, scum, bubbles, clarity, and discoloration--only discoloration was significantly correlated with a perceived water attribute. The lack of significant correlations with these aspects of pollution is somewhat puzzling, particularly in view of the substantially higher levels of correlation between perceived attributes and the chemical measurements which were performed with rigorous laboratory procedures. It may lie in the imprecision of the "objective" ratings. At any rate, Tables 24 and 25 provide some evidence that the respondents were able to perceive levels of water quality.

The questions which are most relevant to the value of a stream to an individual are the basic questions relating to how much

Table 24

CORRELATIONS BETWEEN CHEMICAL AND BIOLOGICAL MEASUREMENTS AND PERCEIVED WATER ATTRIBUTES

Perceived Water Attributes	Biological and Chemical Measurements															
	COD	Coliforms	fecal strep	Total P	Ortho P	NH_3	NO_2	NO_3	SO_4	Cl	TDS 103°	TDS 179°	Water Temp.	D.O.	pH	Water Quality Index
rapidly flowing	-.60	-.53		-.54	-.51	-.56		-.74								.61
transparent	-.67		.56	-.68	-.62			-.69		-.58	-.58	-.65				.60
clean	-.65		.54	-.61	-.56			-.62		-.55	-.59	-.65				.63
smelly																
pleasant			.55													
full of trash													61			-.56
inviting color	-.57		.52	-.55				-.56								
polluted	.69		-.53	.59	.56		.57	.67		.61	.64	.70	58	-64		-.72
healthy	-.63			-.57	-.51			-.54		-.51	-.53	-.60				.63

Underline indicates p is less than .01 other coefficients: p is less than .05
N=12

Table 25

CORRELATIONS BETWEEN OBJECTIVE RATINGS AND PERCEIVED WATER ATTRIBUTES

Perceived Water Attributes	Objective Ratings									
	Rapidity of flow	Riffles	Pools	Sediment	Discolor-ation	Trash on stream	Trash on banks	% Rocks	% Mud	Rural-Urban
rapidly flowing	$\underline{.73}$	$\underline{\underline{.82}}$	-.57	-.53				$\underline{\underline{.77}}$	$\underline{\underline{-.87}}$	
transparent	.62	.63			-.51			.52	$\underline{\underline{-.82}}$	$\underline{-.62}$
clear	.57	.56			-.56				$\underline{\underline{-.78}}$	$\underline{-.69}$
smelly						.58	.64			
pleasant	.59	.61							$\underline{-.66}$	
full of trash						$\underline{\underline{.79}}$				.52
inviting color	.60	$\underline{.70}$	-.54						$\underline{\underline{-.81}}$	
polluted					.54			-.51	$\underline{.73}$	$\underline{.71}$
healthy		$\underline{.71}$			$\underline{-.54}$			.56	$\underline{\underline{-.83}}$	-.61

single underline indicates that p is less than .01
double underline indicates that p is less than .001
N=12

all other listed coefficients: p is less than .05
Correlations between all other combinations were not significant (were less than .05). No significant correlations were found between perceived water attributes and algae, rooted aquatics, floating solids, scum, bubbles, clarity, percent bottom covered with sand, or percent bottom covered with leaves.

the respondent likes the stream, the surrounding area, and the site as a whole, and the questions pertaining to various specific activities he would enjoy at the stream site. The nature of the responses given to the three basic preference questions can be examined by considering the proportions of the total variation in responses which are attributable to various sources. Table 26 lists for each of the three sets of responses the percentages of variation attributable to: differences in the mean responses of observers, differences in the mean responses for streams, and residual variation. The variation due to difference in observer means indicates the extent to which the variation in responses is due simply to a tendency for some observers generally to give higher ratings than others (i.e., on a 1 to 5 scale). It is interesting that observers showed much greater differences in average ratings of streams than in average ratings of surrounding areas; this would indicate that some observers like streams in general more than others. On the other hand, observers show greater agreement for streams than for the surrounding area when rating sites relative to one another. This is shown by the fact that a much greater proportion of total variation is explained by difference between site means for streams than for the surrounding areas. (That is, persons tend to agree as to which streams should receive relatively high or low ratings; thus the mean ratings for sites differ considerably. For ratings of the surrounding areas, disagreement among observers causes the high and low ratings of different observers to cancel each other out, so that the overall means for the various sites to not differ greatly.) Equivalently, the amount of residual variation, which is a measure of disagreement among observers, is greater for ratings of surrounding areas than for streams.

Table 27 presents correlations between responses to the three basic preference questions with the perceived attributes discussed earlier. In addition, the responses to the question "Would you like to come back here?" are also correlated with the perceived attributes. These correlations should indicate the extent to which general liking is determined by the perception of water characteristics.

Most of the possible correlations are statistically significant. The number of observations involved in these correlations is 144 (12 observers x 12 streams) so that even small

TABLE 26

SOURCES OF TOTAL VARIANCE IN RESPONSES TO BASIC PREFERENCE QUESTIONS

(Variance Among Observers and Stream Sites)

	OVERALL RATING (Basic question 1)	RATING OF STREAM (Basic question 2)	RATING OF SURROUNDING AREA (Basic question 3)
PROPORTION OF TOTAL VARIANCE DUE TO:			
Difference between observer means	31.6%	49.9%	22.9%
Difference between site means	30.6%	32.4%	17.2%
Residual	37.8%	17.7%	59.9%
	100.0%	100.0%	100.0%
Significance of variance due to difference between site means [F .01 (11,121) = 2.40]	F = 8.90	F = 20.13	F = 3.16

All significant at the 1% level

TABLE 27

CORRELATIONS BETWEEN PREFERENCE RATINGS AND PERCEIVED WATER ATTRIBUTES

PERCEIVED WATER ATTRIBUTES	PREFERENCE RATINGS			
	Overall Rating	Rating for stream	Rating for surrounding area	Desire to return
rapidly flowing	.25	$\underline{\underline{.32}}$	--	$\underline{.25}$
transparent	$\underline{\underline{.42}}$	$\underline{\underline{.48}}$	.22	$\underline{\underline{.38}}$
clean	$\underline{\underline{.45}}$	$\underline{\underline{.52}}$	$\underline{.29}$	$\underline{\underline{.40}}$
smelly	--	--	--	.24
pleasant	$\underline{\underline{.64}}$	$\underline{\underline{.67}}$	$\underline{\underline{.49}}$	$\underline{\underline{.59}}$
full of trash	-.22	-.19	--	--
inviting color	$\underline{\underline{.44}}$	$\underline{\underline{.59}}$	$\underline{\underline{.26}}$	$\underline{\underline{.47}}$
polluted	-.22	$-\underline{.28}$	--	--
healthy	$\underline{\underline{.46}}$	$\underline{\underline{.54}}$	$\underline{\underline{.38}}$	$\underline{\underline{.38}}$

N = 144
Single Underline indicates p is less than 0.01
Double Underline indicates p is less than 0.001
All other coefficients: p is less than .05

correlation coefficients are statistically significant. A number of correlations between basic preferences and water attributes are quite high. However, these tend to involve those attributes which have been seen to be least closely related to pollution. The highest correlation in each of the four columns is with the attribute "pleasant," which was correlated significantly with only one chemical measurement in Table 24. (The latter was the apparently spurious positive correlation with fecal streptococci.) On the other hand, correlations involving the perceived attribute "polluted" were quite small. The correlation between liking for stream and "polluted" was only -.28. The correlation between desire to come back and "polluted" was not statistically significant. On the other hand, higher correlations were observed for several other attributes which might be associated with pollution, namely: transparent, clean, inviting color, and healthy.

The low association between pollution and basic preference was borne out in direct correlations between the responses to the basic preference questions and the chemical measures. No significant correlations were found.

The data presented in Table 28 refer to the average preference rating of each respondent for the three streams in each of the four organic load groups shown in Table 23. Table 28 shows the proportions of total variation for each of the three basic preference questions which are due to difference between observer means, difference between organic load groups, and residual variation. The variation due to difference between organic load groups, which indicates the extent of agreement among judges as to relative preference among the groups, is quite small for all three basic questions, although it does comprise a statistically significant component for question 2. This provides additional evidence that, for this group of observers and streams, water pollution was not an important determinant of preference.

The results obtained for the basic preference question relating explicitly to streams indicate that although observers may be able to discern pollution reasonably well, they may not consider it of great importance to the attractiveness of the site or even of the stream itself. Liking of the stream does

Table 28

BASIC PREFERENCE QUESTIONS: SOURCES OF TOTAL VARIANCE IN MEAN RESPONSES FOR ORGANIC-LOAD GROUPS

	OVERALL RATING (Basic question 1)	RATING OF STREAM (Basic question 2)	RATING OF SURROUNDING AREA (Basic question 3)
PROPORTION OF TOTAL VARIANCE DUE TO:			
Difference between observer means	80.04	73.04	57.43
Difference between organic-load groups	.66	6.22	1.09
Residual	19.30	20.74	41.48
	100.00	100.00	100.00
Significance of variance due to difference in organic-load group means [F .05 (3,33) = 2.89]	F = 0.38	F = 3.30	F = 0.29

Question 2 significant at 5%

appear to be related to perception of the stream, but seems to involve characteristics such as "pleasantness," which may not be directly related to pollution. It is significant that although pollution is not important to these observers, they exhibit a high level of agreement on the relative attractiveness of streams, implying that some criteria are important to them.

Another way of determining people's preference for given stream sites is to ask what activities they would enjoy doing at the site. Tables 29 and 30, which relate answers to this question to chemical and biological measurements of water quality, separate the activities for which the site is deemed suitable into water-related and not-water-related activities. Water-related activities consist of wading- playing in the water, and fishing. Not-water-related activities consist of relaxing-meditating, enjoying the scenery, and picnicking. In Table 29, no significant correlation was observed for not-water-related activities; the only significant correlations were for water-related activities. All the correlations have the expected sign--more pollution being associated with less desire to undertake an activity at the site--except for the correlation with fecal streptococci, which appears to be spurious as before. Correlations significant at the 0.05 level occur with total phosphates and nitrates, with sulfates, with dissolved solids (both at 103°C and 179°C), and with the Water Quality Index. This pattern is quite similar to that found in Table 24, which shows correlation between chemical measures and perceived water attributes.

Table 30 presents the mean values of each of the activity ratings for each of the four organic load groupings of streams. The analysis of variance was conducted to identify significant differences between organic load groups. The differences between organic load groups were significant for the two water-related activities; at the 0.05 level for fishing and at the 0.01 level for wading - playing in the water. The group means in both of these cases show the expected pattern of differences, namely lower ratings for high levels of organic load. Significant differences at the 0.05 level were also observed for picnicking. However, the group means in this case do not display the expected pattern. Instead, the lowest mean rating occurs for the stream group with the lowest organic load.

Table 29

CORRELATIONS BETWEEN ACTIVITY RATINGS AND CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF WATER

ACTIVITIES AREA SUITED FOR:	Not-water-related activities			Water-related activities	
	Relaxing, meditating	Enjoying the scenery	Picnicking	Wading, playing in the water	Fishing
Chemical & Biological Variables:					
COD					
Coliforms					
fecal strep				.68	.69
Total P				-.52	
Ortho P					
NH_3					
NO_2					
NO_3				-.59	
SO_4					-.51
Cl					
TDS 103°				-.54	-.52
TDS 179°				-.58	-.51
Water temp.					
DO					
pH					
Water Quality Index				.52	

Underline indicates p is less than .01
For all other coefficients p is less than .05

N=12

Table 30

VARIATION OF ACTIVITY RATINGS AMONG LEVELS OF ORGANIC LOAD[1]

(Mean Answers Per Stream Group)

	Level of Organic Load					
	Heavy	Moderate	Low	Very Low	F	P
Not-Water Related Activities:						
relaxing, meditating	2.38	2.28	2.25	2.28	.95	N.S.
enjoying the scenery	2.33	2.16	2.31	2.30	.89	N.S.
picnicking	1.86	1.92	2.00	1.58	3.35	.05
Water-Related Activities:						
wading, playing in the water	1.19	1.36	1.58	1.64	6.89	.01
fishing	1.33	1.33	1.61	1.64	4.14	.05

[1] Answers to question: "Assuming you enjoy all the following activities, and you had come here for recreation, how much would you like to do each of them here?" scale: 1(not at all), 2(somewhat), 3(very much).

The responses pertaining to what activities a subject would engage in if he returned to the site (which are not presented in a table) show no significant differences between streams grouped by organic load. This is consistent with findings to be reported in the next chapter, which indicate that persons are more apt to consider a site suitable for a given activity than to say that they would actually engage in the activity there.

In response to another question in this study, the observers did not identify water quality as a criterion for choosing an area to be made into a park. Definite criteria emerged, but water quality was not one of them.

SUMMARY AND CONCLUSIONS

The studies reported in this chapter provide a basis for identifying the preferences citizens may have for the environmental preservation of alternative stream valleys or parts of a stream valley. The studies indicate that one can expect to find a reasonably high level of agreement on the attractiveness of alternative environments. Generally preferred landscapes are those which are parklike, with mowed grass and scattered large trees, rather than completely natural or wild. In addition, a minority can be expected to have strong positive emotional responses to areas characterized by extreme spaciousness, extreme seclusion and extreme naturalness. Variety, particularly if it is in some way logically or aesthetically ordered, adds significantly to preference. However, specific natural features, in general, are less important than an illusion of naturalness, and this can be most easily lost through the presence of negative characteristics such as junk, ugly development, or other man-made "misfits."

A field study focused on the perception of water quality indicated that persons are able to identify water pollution reasonably well. Their perception of the degree to which a stream is transparent, clean,polluted or healthy was correlated significantly with a number of chemically measured characteristics. However, no significant correlations were found between chemical measures and preference ratings for the stream, its surrounding area, or the area overall. Thus, the connection between objective level of water quality and liking for a site appears to be weak. However, preference for a stream and its surrounding area is related to the observer's perception of whether the stream is transparent, clean, inviting, or healthy. These perceived attributes, in turn, are correlated with the chemical measurements. Observers' judgments of whether a stream is suitable for certain water-related activities are also correlated significantly with a number of chemical variables. Therefore, there is a general consistency between chemical measures of water quality, perceived attributes, and preferences for the stream and surrounding area. However, the study does not indicate that water pollution is a strong determinant of preference. Criteria other than water quality were evidently more important to the observers, who were generally agreed on the relative attractiveness of a stream.

VI. EVALUATION OF EFFECTS: ESTIMATING THE VALUE OF ENVIRONMENTAL PROTECTION

INTRODUCTION

A land use planning and control program such as has been considered in this study would consist of a plan indicating critical areas in the watershed where no development would be allowed. Typically, these would be flood plains, marshy areas, steep slopes, and certain wooded areas. Development would be severely restricted in such areas through a combination of outright public purchase of some lands, which would then become public parks and recreation areas, and of public purchase of conservation easements on other land which would severely restrict its development by its private owners. The public would not have the right of access to these latter areas, unless hiking, fishing, or other right-of-way easements were specifically purchased. The program would also include a well-thought-out set of sewage treatment policies to serve permitted development.

The studies presented in Chapters 2, 3, and 4 indicate the major expected effects of typical urbanization on stream channel enlargement, peak flows, water quality, and stream valley open space. For a given amount of expected typical development in a watershed, these results could be used to calculate the effect of urbanization in the absence of a plan for environmental protection. The difference between these predicted indicators of environmental quality and the level of these indicators before urbanization provides a measure of the maximum deleterious effects which might be avoided by better planning and management. It is not expected, however, that all these effects could be avoided, since some deterioration of the natural environment is inevitable with urbanization.

It should be noted that the results of the studies described in Chapters 2 and 3 would have to be modified considerably in order to describe environmental effects on quality of proper planning. The urban development which would exist under planned conditions would differ from unplanned development not only in location and overall intensity, which have been dealt with in our results, but also in the design of physical features. Planned development should include provisions for improved treatment of sanitary sewerage, strict regulations regarding on-site sewage disposal, and design of storm sewerage (and perhaps the impervious surfaces themselves) to minimize hydrologic impact. The results of our studies, which are based on typical urbanization as it now exists, would not be directly usable to predict urbanization impacts under these conditions.

The environmental impacts associated with fully planned development, incorporating improved design of facilities as well as restrictions regarding location of development, would certainly be smaller than the impacts of development restricted as to location but not as to design. (Impacts resulting from variations in location could be calculated using our results.) Although we cannot say how much less the impacts would be, there is some possibility that the improvements brought about by design changes may exceed the improvements obtainable by restricting location, for a given overall intensity of development. This question is discussed further in the concluding chapter.

Certain effects of urbanization have not been studied as part of this research, such as the effect of construction activity on sediment production. Although the location of development might have some bearing on these effects (e.g., restriction of development on steeply sloping land should reduce sediment production), it is suspected that these effects depend primarily upon factors other than location. Thus, as far as sediment is concerned, the improvement brought about by the plan relative to unplanned conditions would depend largely upon the efficacy and enforceability of regulations of construction practices which might be devised.

The previous chapter has described a series of studies concerned with gaining information which would allow us to estimate the potential value of land use planning to residents of an area, i.e., to translate the physical elements into value terms. The research reported there has dealt with basic issues regarding environmental perception and preferences. This chapter will consider more specifically the question of plan evalution and the calculation of benefits accruing as a result of the plan.

Planning benefits can be considered in two categories: the "fiscal benefits" of environmental protection, including direct economic benefits to taxpayers, and "non-fiscal benefits" which accrue to individuals.

FISCAL BENEFITS

The fiscal benefits include avoidance of increased water supply costs and avoidance of flood losses. The two major relevant aspects of water supply costs are reservoir costs and the costs of water purification.

Avoidance of Reservoir Costs

A Brandywine-type plan would result in higher ground water levels and in more constant streamflow than would be expected under typical urbanization. With such a land use plan, it would be possible to use the stream as water source for a larger percentage of the year than with ordinary urbanization.

It is doubtful, however, that this implies that reservoir capacity could be appreciably smaller. Design capacity for a reservoir depends upon the relationship between seasonal high flow and seasonal low flow, given a constant demand for water [Babbit and Doland, 1955, pp. 170-172]. A planned pattern of land use is likely to have little effect on the amounts of water transported during the periods associated with seasonal high and low flows, since these amounts are determined primarily by variation in rainfall. The effect of a planned land use pattern would be to lengthen the lag time of the effects of small and medium size storms and spread out their hydrographs. (Relevant here are the findings reported by Richard W. Hawkins [1969]. He found that timing delays of the order of half a month would have moderate effects for reservoirs with intermediate storage capacity. However, as the basic streamflow volume is not increased, the upper limit of yield is not raised.)

Even assuming that a substantially smaller reservoir would be adequate with the more constant flow of a Brandywine-planned watershed, it is doubtful that major cost savings would be enjoyed. There would be savings in capital costs of land acquisition and construction for a smaller reservoir, but operating costs would be affected relatively little by a moderate reduction in reservoir size.

Avoidance of Water Purification Costs

Somewhat higher water quality might be expected in a watershed developed according to Brandywine principles as compared with one developed in the ordinary pattern. Therefore, if the water downstream of such a watershed were to be used for water supply, it would be necessary to remove somewhat smaller amounts of impurities.

However, studies indicate that the savings in water treatment costs would not be large. Kneese and Bower state, "Some results are available for the petroleum refining, fruit and vegetable canning, thermal power, and beet sugar industries. In all these instances, industrial costs turn out to be surprisingly insensitive to intake water quality within comparatively wide ranges--especially in regard to aspects of quality that are usually influenced by prior uses and discharge of effluents. Sensitivity is greater to wastes which in most cases are of natural origin, such as chlorides and magnesium " [Kneese and Bower, 1968, p.125].

Continuing to draw from Kneese and Bower: for example, it turned out that downstream water withdrawals to be treated for municipal water supply had to be anywhere from 10 to 250 times as large as the watste discharge (after treatment) upstream before additional waste treatment costs upstream could be justified. Again it appears that the need to prepare potable water cannot justify particularly high standards of quality in watercourses.

This leads to the conclusion that higher water quality must be justified primarily on aesthetic and recreational grounds.

Avoidance of Flood Losses

The plan would result in the avoidance of flood losses in two ways: through reduction in the increase of peak flows associated with urbanization, and through prevention of development in areas subject to flooding. The latter of these is probably the more important. The significant increase in flows due to urbanization is associated primarily with small watersheds and with floods of moderate frequency, i.e., floods occurring every five years or less. Most severe flood damage, however, is associated with large streams and with floods of relatively low frequency (i.e., floods so great that they occur only every 20 or more years). Thus, the most important step in avoiding flood losses is simply to prevent development at locations where flood losses are likely to occur.

NON-FISCAL BENEFITS

These considerations suggest that fiscal benefits of environmental preservation are not the major consideration in evaluation of land use plans. In order to justify the public expenditure on land and easement acquisition and the private costs incurred by restrictions on development, it is clearly necessary to demonstrate that major non-fiscal benefits will occur. These non-fiscal benefits will have to comprise the major portion of the value contributed by the plan. Therefore, the remainder of this chapter is concerned with the evaluation of non-fiscal benefits.

In order to evaluate benefits, they must be expressed in some common measure so that they can be compared with costs. Therefore, estimates of the dollar value of non-fiscal benefits are desired. A major issue is the extent to which the benefits accruing from the plan will be evaluated through economic transactions in the market. The primary market in question here is the market for residential land. Many of the benefits, such as those related to various outdoor activities and to general aesthetic enjoyment, may not be registered in the market directly, and there is some question as to what extent they are registered indirectly.

Techniques have been developed for placing values on various activities, such as hunting and fishing, which are not priced in the market place; these have been applied in many cost-benefit studies. Theoretically, assuming that appropriate values can be determined, it does not matter whether benefits are registered in the market place or not. In the case of evaluating plans for environmental protection, however, it may be necessary to depend largely upon benefits registered in the market place and to demonstrate that these will be large enough so that a major share of the costs will be recovered through higher real estate prices or other mechanisms. Otherwise it may be politically difficult to enact such plans. It is assumed in this discussion that the costs of environmental preservation, i.e., the costs of easements and outright land acquisition, are to be borne within the watershed itself, through some scheme of redistribution of real estate value increments. Very large-scale environmental preservation programs would not be subject to this constraint.

In order for the values created by planning for environmental protection to be reflected in the real estate market, the following two conditions must hold: first, persons must consider it important to have a natural and uncontaminated environment, and second, persons must be aware that their enjoyment of the natural environment depends on its not deteriorating over time, and that the plan, in fact, guarantees this.

There is evidence, contained in the studies reported in the previous chapter and to be reported in this chapter, that many persons are rather indifferent toward environmental conditions other than obvious noxious influences such as junk or extreme pollution. Furthermore, it appears that many persons who do care about the environment do not place corresponding economic values on its enjoyment, perhaps because they perceive the maintenance of environmental quality to be beyond their control.

A second major issue concerning the evaluation of effects is the question of to whom the values will accrue. Since the type of plan discussed here is concerned primarily with future urbanization, the present residents of the area constitute only a portion, perhaps a very small portion, of the persons who will ultimately benefit from the plan. In estimating the value of the plan to future residents, one can either assume that the future residents will constitute a rather typical cross-section of the population of the region, or else that the future residents will be a somewhat untypical group who have chosen the protected area specifically because of the environmental benefits which it offers.

The results of the studies reported in this chapter and the previous chapter indicate that the typical cross-section of suburban residents may not place a sufficiently high value on environmental quality to justify the sort of plan envisioned here. A case will be made in this chapter that it may be necessary for a considerable recruitment process to take place in order to induce residents to the planned area who are willing to pay the costs of the plan, primarily through higher property taxes which would result from higher real estate values. With respect to environmental planning in general, this may be a temporary situation, in that the existence of planned areas is likely to generate additional demands for such planning in the future, particularly as continued urbanization will give a scarcity value to those areas in metropolitan regions which do retain a measure of natural beauty. In addition, it is possible that the preferences of society are changing, so that in the future more value will be attributed to environmental quality. For the present, however, the possibility remains that resident-consumers of environmental quality will have to be recruited from a relatively small segment of the population.

Two major research studies will be summarized in this chapter. The first is concerned with the evaluation which residents make of the natural environment, as it affects their decision to purchase a house. The second study relates the use of nearby streams by residents to the distance of their homes from the stream and to the water quality of the stream.

PREFERENCES AND CHOICE OF RESIDENTIAL ENVIRONMENTS

(A full report on the materials presented in this section may be found in Menchik, Mark D., "Residential Environmental Preferences and Choice: Some Results Relevant to Urban Form," RSRI Discussion Paper Series: No. 46, March 1971.)

Research Procedure

In order to study preferences and choice of residential environments, a home interview questionnaire survey with 457 respondents was conducted by RSRI [Menchik, 1971] which is summarized below. Using a cluster sampling design, samples were drawn at different sampling rates in each of five areas in southeastern Pennsylvania: (1) the Upper East Branch Brandywine Creek area, a predominantly rural area in western Chester County; (2) the Neshaminy Creek area, a predominantly rural area in upper Bucks County; (3) the Northern Chester County area, rural and suburban; (4) the Chester County Towns area, several relatively densely settled towns; and (5) the Main Line area of northeastern Chester County, a relatively wealthy and recently subdivided suburban area. Both Bucks and Chester are suburban counties within the Philadelphia Standard Metropolitan Statistical Area.

Respondents were asked one of two series of questions about the choice of a place to live. When the respondent had lived at his present home for ten years or less and that home had been chosen by the respondent or spouse, then the respondent was asked about the choice of the present home. The question was phrased: "When deciding on a new home in a new area, some people judge a house and area by one set of characteristics, while others judge them by other characteristics. When you were trying to decide on a place to live, what were all of the chatacteristics that were important to you?" The respondent's open-ended reply was written down verbatim by the interviewer.

The remaining respondents, those whose present residence had not been chosen by them, or had lived there more than ten years, were asked about a hypothetical move: "Suppose you were trying to decide on a place to live. What would be all the characteristics that would be important to you?" Again, the response was copied word for word.

The residential preference data used below were obtained from a content analysis of the replies to these questions which led to the established response types. The response types are listed in Table 31. There are four types: responses concerning the natural environment, the non-natural environment, accessibility, and chatacteristics of home and lot.

The respondent's preference for any item (or combination of items) is operationally defined by the number of times the relevant response type(s) was mentioned. The questions were designed to elicit considerations important in the choice of a home (present or hypothetical) and, given the questions' unstructured form, it was assumed that the content of the response would indicate the degree of importance or preference for any locational consideration.

Findings Based on Interviews

Table 32 shows, for a given response-type category, the percent of respondents mentioning considerations from that category in choosing a place to live. For example, as shown in the table, 49% of those asked about choice of present home mentioned at least one consideration involving accessibility and 52% of those asked about hypothetical choice of a home mentioned accessibility. The table also gives the percent

TABLE 31

CONSIDERATIONS IN CHOICE OF A PLACE TO LIVE

(Number and Percentage of Respondents making One or More Responses of Each Type)

	No. of Respondents	% of Respondents
Natural Environment (N)		
1. Ruralness, woodsiness, country-like character of the area	103	22.9
2. Specific mention of an area's prettiness, beauty of surroundings, view	23	5.1
3. Other specific considerations referring to natural environment: climate, weather, topography, etc.	46	10.2
Non-Natural Environment (M)		
Density: presence and number of persons in the vicinity, in general, without references to any of their characteristics		
4. Good: Wanted to be near people	6	1.3
5. Bad: Didn't want to be near (too many) other people	44	9.8
6. Neutral: Just interested in whether there are many persons nearby	2	0.4
Characteristics of people nearby		
7. Good: Wanted to be near a particular kind of person, near my kind of people, etc.	78	17.4
8. Bad: Don't want to live near some stated kind of person, disrespectable, unfriendly, etc.	16	3.6
9. Neutral: Wanted to know what kinds of persons around	3	0.7

TABLE 31 (cont'd.)

	No. of Respondents	% of Respondents
Presence of traffic and non-residential land uses like stores, factories, etc.		
10. Good: Wanted to live near a store, etc.	4	0.9
11. Bad: Didn't want stores, factories, etc., wanted purely residential uses, little traffic	21	4.7
12. Neutral: Interest in presence of stores in vicinity	2	0.4
13. Other considerations referring to the non-natural environment: nice neighborhood, good section of town, quiet, noise, privacy, well-paved streets, etc.	87	19.4
Accessibility (A)		
14. To work	63	14.0
15. To schools	73	16.3
16. To churches	46	10.2
17. To transportation facilities	45	10.0
18. To shopping	69	15.4
19. To other specified activity or convenience, in general	70	15.6
Characterististics of House and Lot (H)		
20. House size, number of rooms, size of rooms	112	24.9
21. Price of house and land, purchasing or renting arrangements, mortgage, etc.	54	12.0

TABLE 31 (cont'd.)

	No. of Respondents	% of Respondents
22. House design characteristics, specific and general, room layout, heating, plumbing, etc.	189	42.1
23. Lot size	94	20.9
24. Other natural environment lot characterisitcs: stream in backyard, soil, landscaping, etc.(for lot, itself, not vicinity)	39	8.7
25. Other non-natural environment lot characteristics: distance from road, sewage facilities, orientation, etc.	30	6.7
Other		
26. Respondent or spouse used to area, lived here before	12	2.7
No. of respondents with usable answers	449	
Respondents with no usable answers	8	

of respondents mentioning various combinations; for example, the percent of persons mentioning both accessibility and house and lot.

Of the four response types, the one mentioned least frequently was that involving the natural environment: 34% of respondents asked about the choice of their present home and 37% of those asked about a hypothetical home mentioned the natural environment. The greatest frequencies of responses were observed for those involving house and lot. The middle ranking response types, in terms of frequency of responses, were accessibility and the non-natural environment, which received roughly an equal number of responses. For none of the response types were the results significantly different for those respondents asked about the actual choice of their own house as opposed to those asked about the choice of a hypothetical house. Therefore, in subsequent analysis the respondent groups are considered together.

Table 33 presents totals for each of the four areas in which the survey was conducted. Variation in the response rate over the five areas is most striking for responses in the natural environment category. The response rate was more than twice as high for the Brandywine area, which is the most rural and natural of the four areas, as for the Main Line, which is heavily suburbanized.

Additional tabulations of the responses were prepared which considered variation with age of household head, total family income, sex of respondent, and chilhood residence of respondent. No significant variation in the percent of respondents mentioning the natural environment was observed for any of these classifications. A most unexpected result was the fact that mention of the natural environment did not increase with income. The lowest percentage of respondents mentioning the natural environment was observed for the $15,000 and over income group.

Findings Relating Interview Responses to Residential Variables

In order to compare respondents' residential preferences with their actual choice of a place to live a detailed study was conducted in which data were collected pertaining to the area near each respondents' residence, using variables paralleling the preference variables. (The 457 respondents were drawn from 92 small areas. The descriptive variables applied to

Table 32

SUMMARY OF RESIDENTIAL PREFERENCES, FOR RESPONDENTS ASKED ABOUT CHOICE OF PRESENT OR A HYPOTHETICAL HOME

(Percentage of Respondents Making One or More Responses for Each Major Category, or Combination of Categories)

Category	Present Home	Hypothetical Home	Total
A (Accessibility)	49%	52%	50%
H (House and Lot)	67%	69%	68%
N (Natural Environment)	34%	37%	35%
M (Non-natural Environment)	46%	50%	48%
NA	17%	18%	17%
NH	19%	20%	19%
NM	20%	20%	20%
AH	26%	32%	28%
AM	23%	29%	25%
HM	24%	28%	25%
Total No. of Respondents	257	151	408
No Usable Answers	2	3	5

Table 33

INTER-AREAL COMPARISON OF RESIDENTIAL PREFERENCES

(Percentage of Respondents Making One or More Responses for each Major Category, or Combination of Categories)

Preference Category	X^2	Brandywine %	Neshaminy %	Northern Chester Co. %	Main Line %	Total %
A	6.368+	56%	42%	52%	42%	50%
H	5.273	63%	67%	78%	66%	68%
N	12.950**	45%	32%	31%	20%	35%
M	6.440+	55%	39%	48%	44%	48%
NA		24%	12%	16%	10%	17%
NH		25%	14%	18%	12%	19%
NM		23%	18%	21%	14%	20%
AH		30%	23%	35%	20%	28%
AM		34%	16%	23%	20%	25%
HM		27%	18%	34%	22%	25%
Total No. of Respondents		163	107	88	50	408
No Usable Answers		2	2	1	0	5

+ Statistically significant $p < .10$
** Statistically significant $p < .01$

each of these areas as a whole, rather than to the respondents' own houses.) Thus, descriptive data were obtained pertaining to the actual level of the natural environment in the neighborhood of the respondent's residence, as rated according to various criteria, and to the levels of the other three response types. The measurements concerning the natural environment included the total perimeter of ponds and length of streams within both a half-mile and one mile of the center of each residential area, the maximum difference in elevation within each area, the percentage of the area in woodland, and a subjective rating of the attractiveness of the natural environment in each area. These measures were combined to form a single natural environment rating.

The descriptive variable corresponding to the accessibility response type is the log of the individual's commuting time. Corresponding to the house and lot response types is the log of the size of the individual's lot. Corresponding to the non-natural environment response type are measurements of the density of structures and traffic within half-mile and one-mile circles of the center of each residential area sample (with these variables expressed in negative form).

Each of the response variables, which are related to these descriptive variables, consisted of the number of responses of a given response type made by an individual divided by that individual's total number of responses.

The correlations between the four response variables and the four descriptive variables were generally very low (Table 34). Only four of the 16 correlations are significant at the 5% level. Two of these correlations were between the natural environment response variable and the descriptive measures of house and lot and the non-natural environment. Considering that the latter two variables both relate to the density of development, these correlations are not surprising. However, the correlation between the natural environment response variable and the natural environment descriptive variables was only 0.057. Taken literally, this result indicates that there is very little relationship between expressions of the natural environment in choice of a residence and actual quality of the environment near the residence one chooses. This result is somewhat contradicted by the result, described above and shown in Table 33, that more than twice as many people living

Table 34

CORRELATIONS BETWEEN RESPONSE VARIABLES AND DESCRIPTIVE VARIABLES

Response Variables	Descriptive Variables			
	Accessibility	House & Lot	Non-Natural Environment	Natural Environment
Accessibility	.133*	-.121	.019	-.057
House and Lot	-.058	.078	.010	-.015
Non-Natural Environment	-.026	.069	.137*	.031
Natural Environment	-.043	.175*	.226*	.057

* - Significant at the .05 level

in the Brandywine area mentioned the natural environment than was the case for respondents living in the Main Line area. The environment in the Brandywine area is certainly more natural than in the Main Line area.

The concept of "naturalness" is only partly measured by the variable N (Natural Environment). An extremely important part of this concept, perhaps the most important, is a low density of development and activity. Low density is measured explicitly by variable M (Non-natural Environment). This variable is significantly correlated with Preference for Natural Environment.

The implications of these data for plan evaluation are somewhat difficult to determine, partly due to the consideration just discussed, namely that natural environment as it relates to the plan involves both variables M and N.

Also, it is difficult to compare response rates involving different aspects of residential choice. The critical factor in the residential choice decision is determined not only by the size of the response rate for each factor, but also by the range over which choice on each factor can be made. For example, house and lot receives the highest response rate, but since housing types are fairly standardized, other factors may be more important in determining the location actually chosen for a residence. Housing, and also accessibility, might be viewed as constraints which must be met, but within which persons optimize other considerations.

The variables under analysis can also be looked at from the point of view of a community which desires to direct its future growth. The community can do little about accessibility since that is determined largely by its location within the metropolitan area. It can determine housing types to only a limited degree through zoning and subdivision controls, but the home building industry will continue to make the major decisions concerning style and design of house. The community, however, can have a major effect on overall density of development and pattern of preserved natural amenity.

PERCEPTION AND USE OF STREAMS IN SUBURBAN AREAS

The second major study relevant to the estimation of the value of environmental programs is concerned with how persons perceive and use the streams they live near. Specifically, it is concerned with their judgment of the stream's attractiveness, the extent to which nearby residents visit and use the stream, the effect they believe it has on their property value, the extent to which they are aware of the severity of pollution of the stream, and the actions they would be willing to take to abate the pollution. The research carried out on these subjects is discussed fully in Coughlin, Hammer, Dickert and Sheldon [1972] and is summarized below.

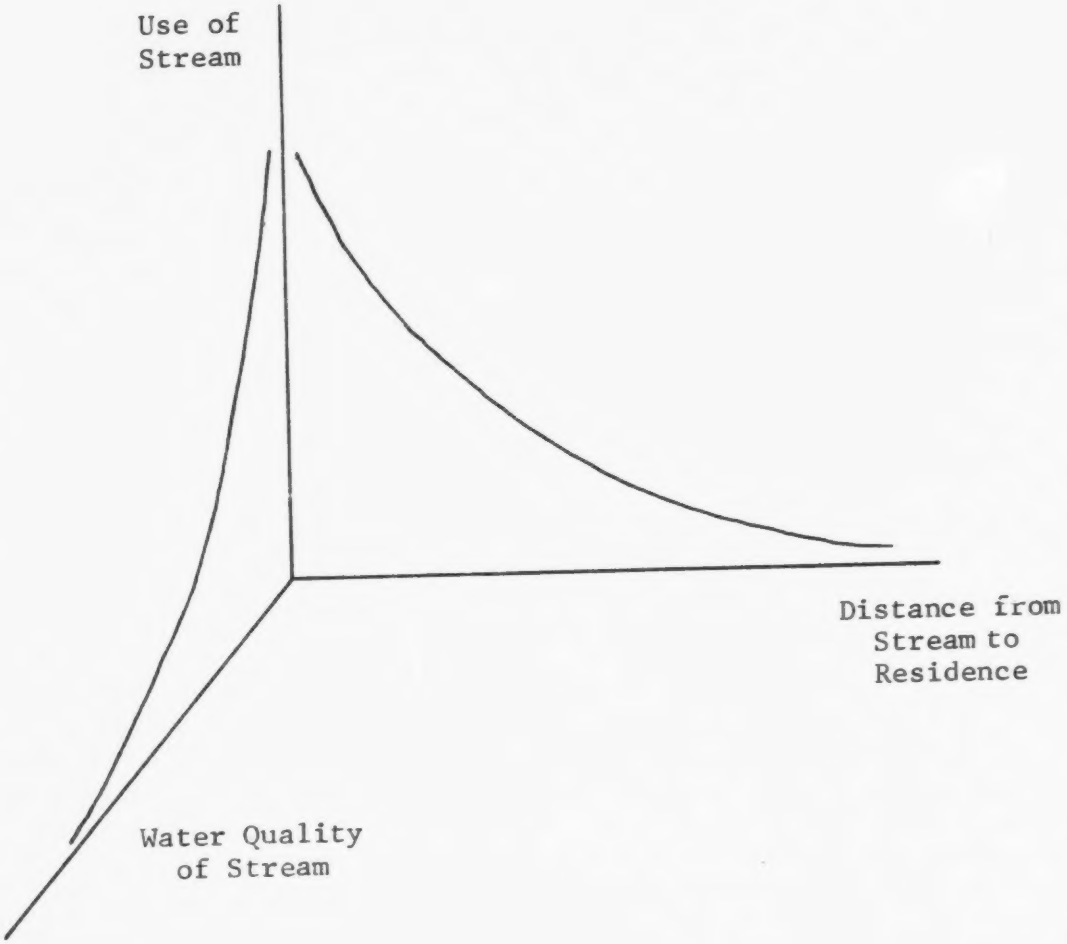
The focus of the analysis is on how these attitudes and uses vary with the level of water quality of stream, and with distance of residence from the stream. The concern with water quality arises from the fact that maintenance of relatively high water quality is one of the major effects expected from a plan of land use and waste management. The perception of water quality levels by neighbors and the use that they actually make of the stream given their perceptions and the objectively measured levels of water quality must be known if one is to evaluate the benefits resulting from the plan's effect on water quality.

The concern with distance of residence of respondent from stream makes it possible to determine how the benefits due to recreational and aesthetic functions provided by a stream fall off with distance from it. With this information it is possible to estimate how total recreational and aesthetic benefits vary depending on the pattern and amount of nearby development, and thus to define a service area for the recreational and aesthetic functions of a stream.

The effects of water quality and distance to residence are conceptualized in Figure 10, which indicates that the more polluted a stream is, the less a neighbor will use it for recreation or value it as an aesthetic asset. Also, the further away he lives, the less he will use or value the stream.

Figure 10

CONCEPTUAL RELATIONSHIPS BETWEEN WATER QUALITY OF STREAM, DISTANCE OF RESIDENCE FROM STREAM, AND USE OF STREAM


Use of Stream
Distance from Stream to Residence
Water Quality of Stream

The Effect of Distance from Residence to Stream

In order to concentrate on the effect of distance from house to stream, interviews were conducted with a total of 222 households, located in the vicinity of 5 stream reaches. Respondents were asked which of a number of activities they considered the stream to be suitable for and which of those activities they actually engage in at the stream. They were also asked a number of questions concerning the effect of the stream on property values.

In order to determine the effect of distance to residence on attitudes and activities, it is necessary first to consider two other sets of factors: socio-economic characteristics of respondents and the characteristics of each stream. The type of relationship wherein these three factors interact to produce a given response would logically be a multiplicative relationship; that is, for an effect to take place, all three factors would have to be non-zero. For example, when predicting the use of a stream by a respondent, his distance to stream cannot be important if his socio-economic characteristics are such that he would not use the stream in any case. Similarly, socio-economic characteristics alone will not imply use by a respondent who lives near an extremely polluted stream. Therefore, a multiplicative (non-linear) model was employed which was fit statistically, for each dependent variable, by the conventional means of converting to logarithmic form and using linear regressions.

The use of a multiplicative model required a single socio-economic variable, which would combine the various socio-economic characteristics to form an "index" for each respondent. The most consistently significant of all charcteristics used in forming this index was number of children in household. It is significant at the 1% level for responses to whether they go to fish, sit, picnic, play games, walk, or ice skate. Other characteristics which are significant at the 1% level are percent-married and percent-professional for whether the stream lends itself to (is suitable for) hunting; and percent-craftsmen for whether the respondents would use the stream if it were in public ownership. These relationships, and a number of others which are significant at the 5% level, indicate that in addition to number of children, occupational status, education, and income should be considered in estimating the use which residents would make of a nearby stream.

A small constant (c) was added to the socio-economic indices in order to avoid indices close to zero which in log form would dominate the regression results.

It would have been desirable to have a single variable expressing stream characteristics similar to the single socio-economic variable. However, with only five streams in the sample, it was impossible to determine the appropriate weightings for the various water quality and other stream characteristics. Thus, the procedure was to utilize a set of "dummy" variables to assign an "effect" to each stream without providing any indication as to why differences in effect appear between the various streams.

Therefore, it was hypothesized that responses would be related to distance to streams, times socio-economic index, times a stream-specific factor; with each of these three factors raised to various exponents.

Findings Concerning Effect of Distance of Residence from Stream

The equations expressing the effect of distance, socio-economic index, and stream characteristics are given in Table 35. It will be seen that the socio-economic index is significant at the 0.05 level for every dependent variable. The fact that socio-economic characteristics provide a large proportion of the explanation of residents' attitudes toward, use of, and evaluation of nearby streams is not unexpected. In fact, most analyses concentrate on such characteristics to the exclusion of other independent variables. Knowledge of such relationships, however, is of limited value to the planner who is concerned with delineating land development patterns which are intended to be relatively permanent and cannot be easily changed. For the planner, relationships involving distance from the stream are the most useful.

Distance berween residence and stream is significant at the 0.05 level for nearly all of the activities. However, it is significant only in scattered instances for the remaining questions. For example, distance to residence appears to have little effect upon a person's knowledge that the stream exists, upon the reasons why the stream is not visited, upon the degree to which people would rather live closer to the stream, and upon whether they think their house would be worth more were it located nearer the stream. However, the dollar amount of increase in value estimated by the respondents does fall off significantly with distance of present residence from the

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Table 35

SUMMARY OF REGRESSIONS EXPLAINING SURVEY RESPONSES BY DISTANCE ALONG PUBLIC WAYS BETWEEN STREAM AND RESIDENCE, SOCIO-ECONOMIC INDEX, AND STREAM-SPECIFIC DUMMY VARIABLES

Response to Survey Question	STREAM-SPECIFIC DUMMY VARIABLES (Regression Coefficients) 1	2	3	4	5	SOCIO-ECONOMIC INDEX log ([illegible]) Coefficient	Standard Error	Best Value of C	DISTANCE ALONG PUBLIC WAYS log D Coefficient	Standard Error	MULTIPLE R For Variation Around Mean
1 Know stream is near	1.000	.595	1.007	.959	.657	----	----	----	.0410	(.0464)	.5217
2 Know its name	.978	.994	.999	.973	.820	3.2115	(1.6041)	.5	-.0673	(.0406)	.3734
3 Usually aware of it	.597	.969	.829	.936	.877	2.1851	(0.8610)	.0	-.0478	(.0625)	.2370
4 Go to stream	.673	.954	.759	.622	.475	1.7531	(0.5518)	.0	-.1850	(.0566)	.4243
5 Stream good for hunting	.364	.345	.348	.113	.408	3.2059	(0.8755)	1.0	-.2133	(.0961)	.3230
7 Stream good for fishing	.450	.360	.626	.288	.564	----	----	----	-.3048	(.0939)	.3370
9 Stream good for wading	.322	.226	.495	.168	.371	0.9461	(0.3821)	.1	-.2023	(.0942)	.3195
11 Stream good for sitting	.450	.256	.542	.164	.540	----	----	----	-.2784	(.0963)	.3681
13 Stream good for picnicking	.431	.270	.609	.031	.332	----	----	----	-.2293	(.0936)	.3981
15 Stream good for playing games	.362	.264	.583	.114	.366	1.0370	(0.4467)	.0	-.1649	(.0953)	.3680
17 Stream good for walking	.601	.411	.589	.373	.560	----	----	----	-.2361	(.1014)	.2608
19 Stream good for bird watching	.336	.255	.307	.245	.340	0 8550	(0.4240)	.1	-.0652	(.0954)	.1703
21 Stream good for ice skating	.538	.382	.596	.404	.310	3.6932	(1.4824)	1.0	-.2337	(.0991)	.3378
29 Stream good for at least one activity	.978	1.015	.952	.947	.889	4.7330	(2.4757)	1.0	-.0809	(.0350)	.3131
6 Engage in hunting	.018	.107	.108	.063	.094	----	----	----	-.0570	(.0568)	.1498
8 Engage in fishing	.201	.064	.436	.284	.253	3.0411	(1.0222)	1.0	-.2429	(.0921)	.4241
10 Engage in wading	.056	.053	.259	.124	.188	----	----	----	-.0554	(.0690)	.2631
12 Engage in sitting	.232	.189	.485	.131	.190	1.7902	(0.5990)	.5	-.2605	(.0844)	.4165
14 Engage in picnicking	.201	.104	.533	.076	.162	2.9492	(0.8960)	1.0	-.2495	(.0764)	.5207
16 Engage in play.games	.161	.071	.469	.073	.142	2.9683	(0.7379)	1.0	-.1525	(.0737)	.4797
18 Engage in walking	.468	.284	.351	.401	.370	2.3143	(0.5780)	.5	-.2204	(.0983)	.3416
20 Engage in bird watching	.100	.092	.137	.151	.148	2.9962	(0.7198)	1.0	-.1464	(.0656)	.3109
22 Engage in ice skating	.380	.285	.444	.447	.072	0.7835	(0.1867)	.0	-.3074	(.0886)	.4353
30 Engage in at least one activity	.974	.993	.892	.929	.908	2.1265	(0.9674)	.0	-.1282	(.0471)	.2718
31 Don't go there: go elsewhere	.020	.072	.069	.167	.064	----	----	----	.0635	(.0519)	.1827
32 Don't go there: stream polluted	.208	.010	.149	.126	.018	----	----	----	.0750	(.0619)	.7615
33 Don't go there: other reasons	.158	.106	.183	.481	.434	3.7682	(1.2555)	1.0	-.0061	(.0853)	.4207
34 Would use stream if publicly owned	.436	.457	.394	.531	.573	3.9043	(1.0692)	1.0	-.2323	(.1003)	.3019
35 Would like to live closer	.245	.025	.013	.033	.252	----	----	----	-.0234	(.0559)	[illegible]
36 Would like to live fronting	.150	.171	-.014	-.001	.210	----	----	----	-.0846	(.0539)	.2751
37 Would like to live with view	.095	.034	.027	.084	.088	----	----	----	.0453	(.0506)	.1625
38 Would like to live within 5-minute walk	-.001	-.005	.002	.003	.025	0.2829	(0.1136)	.1	.0088	(.0138)	.2181
39 House be worth more	.221	.028	.040	.100	-.012	2.7635	(1.2724)	1.0	-.0524	(.0574)	.3595
40 How much more	4.872	3.607	-.220	2.051	2.351	----	----	----	-3.1238	(1.6535)	.2364
41 Notice pollution	.637	.665	.714	.555	.313	1.7010	(0.7245)	.0	-.1005	(.0952)	.3486
42 Others commented on pollution	.287	.240	.293	.469	.177	3.6936	(1.3869)	1.0	-.2534	(.1132)	.2590
43 Sum of actions: letters	.882	1.318	.691	.745	1.027	----	----	----	-.4458	(.2404	.2029
44 Sum of actions: direct action	.442	.904	.535	.573	.849	4.1427	(1.4049)	1.0	-.4682	(.1801)	.3157
45 Would take no action	.116	1.239	.325	.503	.299	----	----	----	.3101	(.1765)	.4766
46 Accept more taxes to abate pollution	.460	.447	.334	.435	.421	2.4669	(0.8828)	.3	-.1980	(.1012)	.2251
47 Environmental concern	.309	.246	.292	.295	.281	3.7731	(0.8736)	1.0	.0611	(.0789)	.3516

stream. Similarly, whether the respondents notice pollution, and whether they are willing to take action or pay additional taxes, is unrelated to distance--except that whether they are willing to take direct action does fall off significantly with distance. This is reasonable in that it takes a greater commitment to take direct action, such as legal action, participation in clean-ups, or picketing than it does simply to write letters; and people who live close to the stream and experience it more frequently are more likely to have such a commitment.

In order to make it easier to interpret the equations listed in Table 35, these equations have been computed on a relative scale in which the activity level (the estimated value of the dependent variable) at 100 feet from the stream is set at 100% for every activity (that is, for each dependent variable). This level may be called the base-level use rate, that use rate by residents which is unaffected by distance of residence to stream [Coughlin, Taieb, and Stevens, 1972]. The distances at which the activity level is 90%, 80%, ... 10% of the base-level use rate are computed and summarized in Tables 36 and 37. Table 36 relates to distances measured along the straight line between residence and point of access on the stream; Table 37 refers to distances measured along public rights of way. Curves corresponding to Table 36 are given in Figure 11. For convenience, distances greater than a mile are not plotted.

Examination of Figure 11 shows that the number of residents who take a walk along the stream drops off relatively slowly with distance. People living a mile from the stream are only half as likely to walk along the stream as are people who live only 100 feet from the stream. The curve for more specific activities drop off more quickly than does the curve for walking. At the extreme, persons living a mile from the stream are only 5% as likely to go to the stream to picnic as are persons living 100 feet from the stream.

The rate at which each use-rate curve falls off with distance can be summarized in at least two ways. The first is by the slopes of the curves in Figure 11. These are determined by the coefficient of distance from the stream (D), and the activity level of residents living 100 feet from the stream. These coefficients may be read directly in Table 35; the activity level at 100 feet may be estimated roughly as the

Table 36

SUMMARY OF REGRESSIONS EXPLAINING SURVEY RESPONSES MEASURING DISTANCE BETWEEN STREAM AND RESIDENCE, ALONG SHORTEST STRAIGHT LINE

(Other Variables as in Table 35)

	Response to Survey Question	Log of Distance Along Shortest Straight Line		
		Coefficient	Standard Error	Multiple R
1	Know stream is near	-.0273	(.0482)	.5202
2	Know its name	-.0059	(.0423)	.3585
3	Usually aware of it	-.0706	(.0651)	.2370
4	Go to stream	-.1463	(.0902)	.4150
5	Stream good for hunting	-.1684	(.0589)	.3144
7	Stream good for fishing	-.3334	(.1023)	.3434
9	Stream good for wading	-.2231	(.0975)	.3234
11	Stream good for sitting	-.2297	(.1006)	.3510
13	Stream good for picnicking	-.2814	(.0965)	.4096
15	Stream good for playing games	-.1643	(.0987)	.3667
17	Stream good for walking	-.2264	(.1054)	.2542
19	Stream good for bird watching	-.0913	(.0988)	.1753
21	Stream good for ice skating	-.3257	(.1022)	.3636
29	Stream good for at least one activity	-.0134	(.0367)	.2760
6	Engage in hunting	-.0644	(.0589)	.1526
8	Engage in fishing	-.2078	(.0856)	.4114
10	Engage in wading	-.1448	(.0712)	.2991
12	Engage in sitting	-.2614	(.0877)	.4136
14	Engage in picnicking	-.3138	(.0783)	.5369
16	Engage in playing games	-.1970	(.0761)	.4884
18	Engage in walking	-.1719	(.1021)	.3284
20	Engage in bird watching	-.1341	(.0681)	.3035
22	Engage in ice skating	-.2615	(.0927)	.4178
30	Engage in at least one activity	-.1249	(.0498)	.2646
31	Don't go there: go elsewhere	.1264	(.0533)	.2266
32	Don't go there: stream polluted	.1201	(.0639)	.2777
33	Don't go there: other reasons	-.0585	(.0885)	.4226
34	Would use stream if publicly owned	-.1812	(.1047)	.2850
35	Would like to live closer	-.0265	(.0684)	.3275
36	Would like to live fronting	-.0891	(.0653)	.2800
37	Would like to live with view	.0431	(.0525)	.1405
38	Would like to live within 5-minute walk	.0031	(.0143)	.2148
39	House be worth more	.0112	(.0545)	.35[illegible]
40	How much more	-.5625	(1.7288)	.2019
41	Notice pollution	-.0203	(.0989)	.3629
42	Others commented on pollution	-.0896	(.1176)	.2479
43	Sum of actions: letters	-.2979	(.2505)	.1796
44	Sum of actions: direct action	-.4580	(.1877)	.3105
45	Would take no action	.4488	(.1821)	.4816
46	Accept more taxes to abate pollution	-.1340	(.1055)	.2060
47	Environmental concern	.0072	(.0940)	.3021

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Table 37

ESTIMATED DISTANCE OF [illegible]

	[illegible]										
	100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
1 [illegible]	Positive										
2 Know the [illegible]	100	---	---	---	---	---	---	---	---	---	---
3 [illegible]	100	---	---	---	---	---	---	---	---	---	---
4 Go to [illegible]	100	417	1008	3131	---	---	---	---	---	---	---
5 Stream [illegible] hunting	100	192	369	710	1364	2021	5036	---	---	---	---
7 fishing	100	190	360	684	1290	2464	4818	---	---	---	---
9 wading	100	191	377	731	1134	2752	---	---	---	---	---
11 sitting	100	127	350	655	1255	2142	4065	---	---	---	---
13 picnicking	100	192	377	737	1471	2760	---	---	---	---	---
15 playing games	100	210	419	810	1506	4017	---	---	---	---	---
17 walking	100	221	489	1060	[illegible]	[illegible]	---	---	---	---	---
19 bird watching	100	316	1468	---	---	---	---	---	---	---	---
21 ice skating	100	211	444	935	1970	4157	---	---	---	---	---
23 leisurely activities (sum)	100	170	338	448	827	1493	2550	4806	---	---	---
25 at least 1 leisurely activity	100	180	323	569	1062	1672	3365	---	---	---	---
27 all activities (sum)	100	211	444	916	1971	4157	---	---	---	---	---
6 Engage in hunting	100	184	340	616	1153	2124	3924	---	---	---	---
8 fishing	100	157	290	469	787	1708	2127	3616	---	---	---
10 wading	100	184	339	623	1166	2110	3682	---	---	---	---
12 sitting	100	167	283	468	787	1310	2191	2685	---	---	---
14 picnicking	100	165	272	448	737	1217	2023	3316	---	---	---
16 playing games	100	179	321	575	1029	1844	3303	---	---	---	---
18 walking	100	205	427	870	1791	3654	---	---	---	---	---
20 bird watching	100	161	259	416	668	1075	1776	2779	4447	---	---
22 ice skating	100	169	285	480	811	1398	2370	3594	---	---	---
24 leisure activities (sum)	100	199	394	753	1555	3067	---	---	---	---	---
26 at least 1 leisurely activity	100	204	414	817	1778	3523	---	---	---	---	---
28 all activities (sum)	100	225	508	1146	2253	---	---	---	---	---	---
30 at least 1 activity	100	720	5150	---	---	---	---	---	---	---	---
31 Don't go there - go elsewhere	Positive										
32 Don't go there - stream polluted	Positive										
33 Don't go there - other reasons	100	---	---	---	---	---	---	---	---	---	---
34 Would use stream if publicly owned	100	211	446	913	1700	4210	---	---	---	---	---
35 Would like to live closer	100	283	801	2265	---	---	---	---	---	---	---
36 fronting	100	150	326	587	1060	1913	3451	---	---	---	---
37 within view	Positive										
38 within 5 minute walk	Positive										
39 House be worth more	100	186	346	642	1191	2220	4124	---	---	---	---
40 How much more	100	161	259	417	672	1091	1741	2603	4512	---	---
41 Notice pollution	100	557	3007	---	---	---	---	---	---	---	---
42 Others contacted on pollution	100	197	368	767	1507	2658	---	---	---	---	---
43 Sum of actions: letters	100	217	471	1021	2218	4527	---	---	---	---	---
44 Sum of actions: direct action	100	184	334	622	1144	2104	3869	---	---	---	---
45 Would take [illegible] action	Positive										
46 Accept more taxes to abate pollution	100	215	462	994	2138	4595	---	---	---	---	---
47 Environmental concern	Positive										

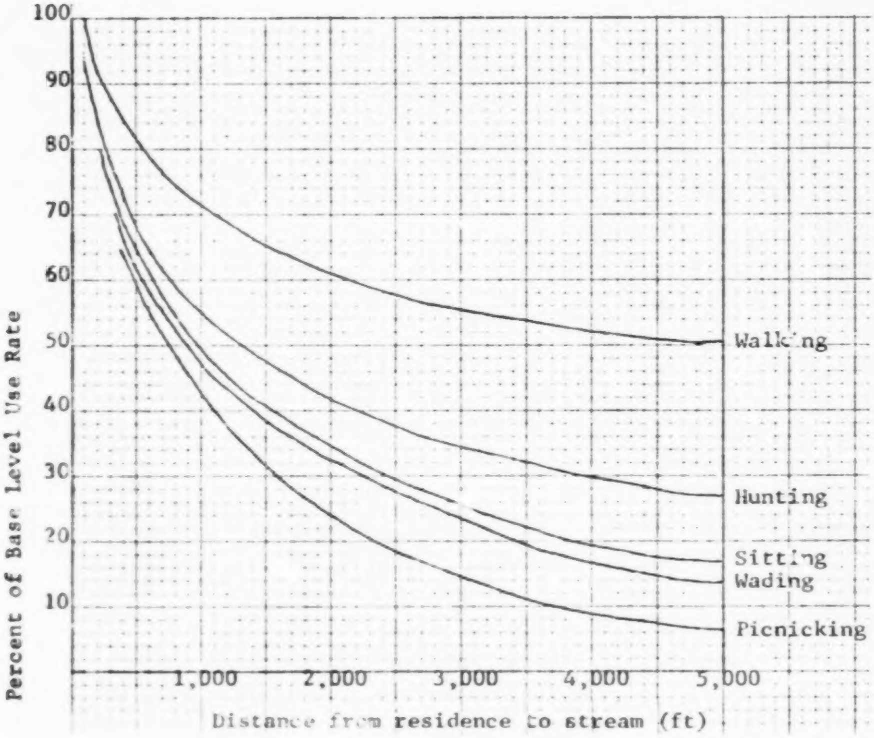
--- Denotes distance exceeding one mile

"Positive" indicates that variable increases with distance from stream

Figure 11

PERCENT OF BASE LEVEL USE OF STREAM SITE
BY DISTANCE OF RESIDENCE FROM STREAM,
FOR SELECTED ACTIVITIES

(distance is Straight-Line distance from
residence to nearest point on stream)



average of regression coefficients for the dummy variables which are found in the same table.

The second is the "effective service radius," that distance at which use of the stream drops to a given fraction of the use rate by residents who live near the stream. If effective service is defined as, say, 20% of base-level service (that is, each resident at the effective service radius is getting one-fifth as much use out of the stream as those who live next to it), then we can observe that the effective service radius for picnicking is about 2,500 feet, for wading about 3,300 feet, for sitting about 3,900 feet, for fishing about one mile, and for the remaining activities, including walking, more than one mile.

The effective service radius can be mapped directly to indicate the residential locations for which the existence of the stream is important. Such a map, presented in Figure 12 for a portion of Bucks County, shows boundary lines corresponding to 20, 40, and 60% of the use rate by residents who live 100 feet from the stream. The data for drawing these lines is taken from a curve typical of those in Figure 11, specifically the average of the curves for sitting, wading, and bird watching. Service boundary lines are also drawn for the downstream portion of Poquessing Creek. This considerably smaller creek does not fall within the size range of our sample, and therefore, our estimated curves (Figure 11) may not be appropriate for it. In general, one might expect a somewhat lower total level of use, and a more rapid decline of use with distance than would be expected for a larger stream typical of our sample. Therefore, less confidence should be placed in the service area boundary lines drawn for Poquessing Creek than in those drawn for Neshaminy Creek.

It is evident from Figure 12 that the majority of residential locations lie beyond the effective service radius, and therefore, receive relatively little use benefit from the existence of the stream. However, the total use which is made by the many residents who live beyond the effective service radius is very substantial. Since the extent of our household survey was limited and since we did not do a direct survey of users at the stream, we cannot present data on the percent of users who live beyond the effective service radius. However, it is possible to estimate the number of users by projecting the use curves, multiplying the resulting projected use rates by the number of people living at each location and summing.

Since the use curves tend to flatten out beyond the effective service radius, this area may well generate a significant proportion of all stream users. For example, the "sitting" curve lies in the midst of all the specific activity curves. Therefore, it may be thought of as an average case. If we assume uniform population densities as we go away from the stream, we can calculate directly from that curve that 158 visits (in arbitrary units) are generated by persons living within the effective service (20%) radius. (This is computed by taking the average use rate in each 1,000-foot distance band and summing, i.e., 63 + 42 + 30 + 22 = 158.) In order to generate another 158 visits, one would have to go out nearly another 3 miles--that is, a total service area of somewhat less than 4 miles. Thus we can hypothesize that if the streams are 8 miles or more apart on the average, more than half of the users will come from beyond the 20% effective service radius. Study of the map of Bucks County will indicate that although there are a number of localities where streams are eight or more miles apart, typically streams are somewhat closer. Therefore, substantially more than 50% of the users of a Bucks County stream can be expected to live within the 20% effective service radius.

The Effect of Water Quality

Research Procedure

Observations on five streams, which were designated in the previous section, are not sufficient to provide a statistically convincing explanation of relationships between water quality and the perception and use of streams. Therefore, a mail questionnaire was administered to residents living near thirty of the water quality monitoring stations operated by the Bucks County Planning Commission. In contrast to the survey described in the previous section, in which residents living at various distance up to a mile were chosen, in this survey residents were chosen who lived as close as possible to the stream. The primary purpose of the analysis of the previous section was to determine how use and perception vary with distance of residence, while the primary purpose of this section is to determine how they vary with water quality.

Figure 12

ESTIMATED DISTANCE FROM STREAM FOR 20%, 40% and 60% OF BASE LEVEL USE RATE OF TYPICAL ACTIVITY

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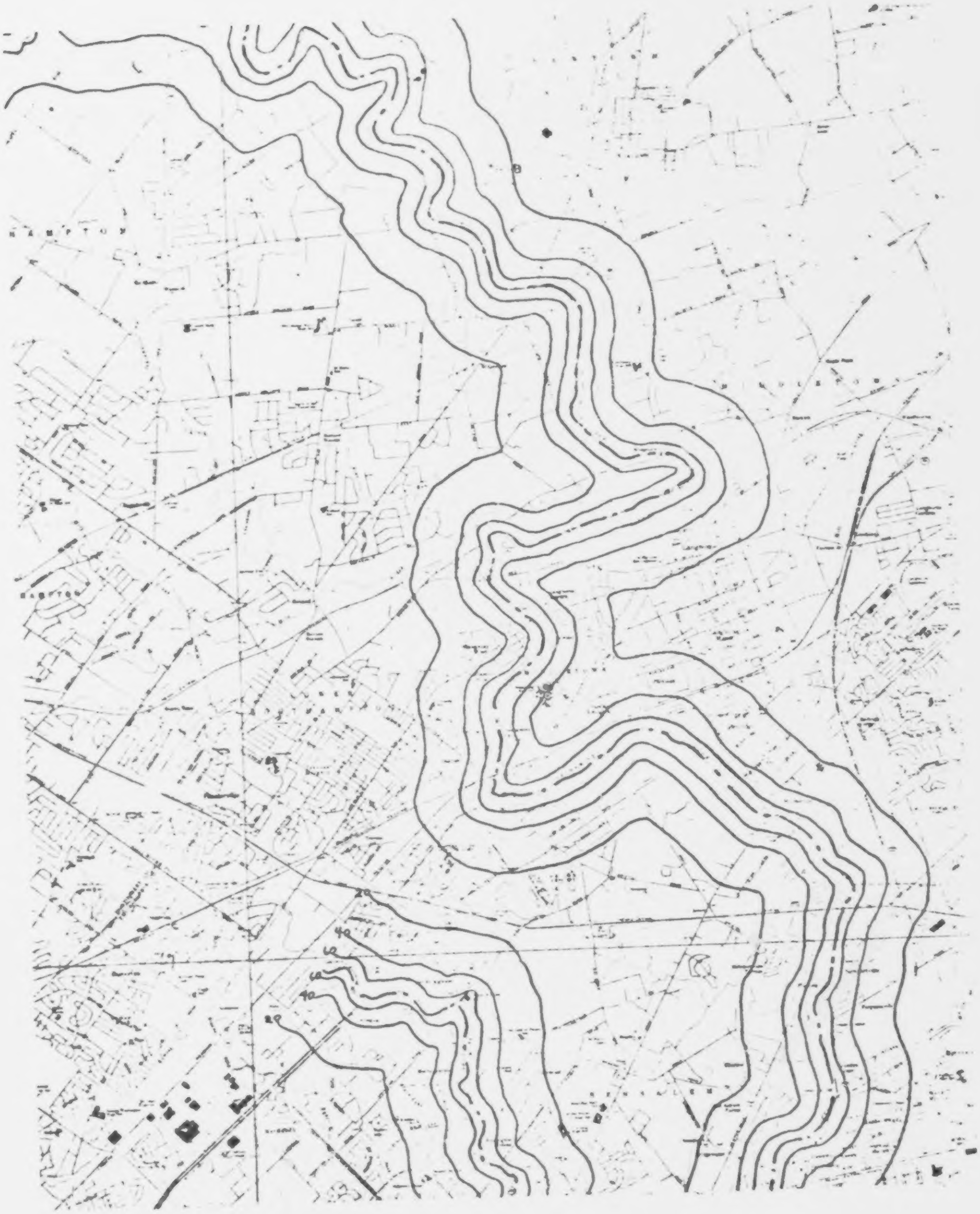
HAMPTON
20
40
60
60
40
20

A total of 312 usable questionnaires were returned out of 731 which were believed to have reached their addresses. The resulting response rate of 42.7% is unusually high for a mail questionnaire, and may even understate the actual response rate, since a number of the questionnaires had to be sent out with incomplete addresses, and, therefore, may never have reached the intended respondents. Because of the high response rate, it is felt that sampling bias, which is inherent in mail surveys, is probably not a major problem.

The Data

Two basic sets of data are involved, that derived from the questionnaire survey described above, and a set of chemical measurements of stream water quality.

Chemical data on water quality were furnished by the Division of Natural Resources, Bucks County Planning Commission. These data consisted of measurements of the following chemicals and chemical properties which had been made, generally speaking, on a monthly schedule.

Conductivity at 25°C
Dissolved Oxygen (% saturated)
CO_2 (mg/l)
Total alkalinity (mg/l)
pH
Nitrates as N (mg/l)
Nitrites as N (mg/l)
Phosphates as PO_4 (mg/l)
Chlorides as Cl (mg/l)
Turbidity (mg/l)
Hardness as $CaCO_3$ (mg/l)
Color
Total Dissolved Solids (mg/l)
Loss on Ignition (mg/l)
Fixed Solids (mg/l)
SO_4 (mg/l)

In order to summarize the data, and obtain indicators of the typical condition of each stream, the following measures were computed for each chemical:

Average of all measurements during the year
Median of all measurements during the year

To obtain indicators of extreme conditions the following were chosen for each stream:

Second worst condition observed
July measurement (or average of July measurements)

The second worst reading was specified instead of the worst, since the worst was more likely to fall outside of the normal range of conditions and, therefore, not be typical of its stream for most years. Worst condition is usually associated with the highest concentration of a given chemical; however, for some measures such as dissolved oxygen over most of the range, the worst conditions are indicated by the lowest numbers. For a number of indicators (such as pH, total solids, and dissolved oxygen over extreme ranges) a moderate reading is associated with high water quality, whereas, both low readings and high readings are associated with low water quality. In order to identify the second worst reading for such indicators the two largest and the two smallest readings were plotted on curves relating chemcial readings to water quality [Brown, McClelland, Deininger and Tozer, 1970], and the reading corresponding to the second lowest water quality was identified.

July readings were analyzed since July tends to be a month of relatively high pollution, and since July data were available for all stations.

For purposes of analysis, and for ease of communication to persons who are not well-versed in the chemistry of water pollution, a list of 16 chemical measurements is awkward. It would be much more desirable to have a single indicator of water quality. Because of the complexity of water chemistry and the many uses for which the quality of water might be considered, there is no generally accepted indicator of water quality. However, work to develop and refine a Water Quality Index is being done by Brown, McClelland, Deininger and Tozer [1970]. Their Index has been developed by a carefully iterated series of questions between the four researchers and a panel of 142 regulatory officials, public utility managers, consulting engineers, academicians, and others. The panel members identified 11 characteristics which they considered to be most important with respect to overall water quality. Each panel member was then "asked to draw a curve, which in (his) judgment, represented the variation in level of water quality produced by the various possible measurements of each respective (characteristic)." The results were then averaged to produce a curve indicating the significance for water quality of given concentrations of each characteristic. The respondents were also asked to weight the importance to overall water quality of each characteristic. The rating curves and importance weights were applied to the available data on the 26 Bucks County streams to produce the Water Quality Indexes listed in Table 38. Because the available data lacked some of the characteristics specified in the Water Quality Index, the Index was computed on only 7 specified characteristics, which would have constituted 80% of the possible high score had all 9 characteristics been included. (One of the characteristics for which data were lacking was "Departure from equilibrium temperature," a measure which was designed to capture major effects such as are caused by a large infusion of warm water from an electric generating plant. Streams in the sample would not register on this characteristic. The other characteristic lacking data was BOD-5. This is a somewhat more serious deficiency, since BOD levels are likely to vary among the 26 streams.)

An additional "index" of water quality was derived by taking the first principal component of the set of 16 chemical measurements, as will be discussed below. The score of each stream site on this component was calculated to serve as an index; these values are listed in Table 38.

Analysis and Results

Individual Indicators of Chemcial Water Quality

In order to determine the relationships between level of water quality and the use and perception of the streams, regressions were run in which each of the 16 chemical measurements appeared separately. They were of the following form:

$$X_i = a_1 + a_2(\text{log Distance to Stream}) + a_3(\text{No. of Children}) + a_4(\text{log Drainage Area}) + a_j\ (\text{Chemical } j) \ldots\ldots\ldots + a_{17}\ (\text{Water Quality Index}).$$

where X_i $(i = 1 \ldots 50)$ is a dependent variable derived from the questionnaire responses, and

Table 38

SUMMARY MEASURES OF WATER QUALITY

	Year Average		Median		2nd Worst		July	
Stream Site[1]	WQI	Score on 1st Component	WQI	Score on 1st Component	WQI	Score on 1st Component	WQI	Score on 1st Component
1	74.4	-2.094	75.9	-2.161	72.8	-1.748	73.0	-1.397
2	67.6	.116	70.1	- .216	64.8	- .561	61.1	- .070
3	75.8	-2.073	72.3	-2.007	63.9	-2.080	76.4	-1.086
5	68.1	-1.804	69.6	-2.077	63.8	-1.924	67.1	-2.070
7	60.0	- .126	66.5	- .544	55.4	.277	64.0	-1.492
8	72.0	-1.283	71.6	- .895	64.1	-1.216	71.5	- .950
9	75.6	-1.409	75.9	-1.294	66.5	- .987	77.6	-1.234
10	74.5	-2.927	76.9	-2.872	65.8	-2.106	75.1	-1.938
11	67.6	-2.516	72.9	-2.890	53.8	-2.882	66.2	-2.632
12	69.2	-2.239	73.8	-1.197	57.6	-1.765	67.1	-1.392
13	45.8	9.122	45.3	10.708	52.2	6.448	38.0	9.825
14	53.1	4.454	58.9	3.908	51.7	3.957	48.6	2.344
15	60.1	.602	62.8	.390	54.6	.953	59.0	1.027
16	57.1	2.014	61.1	.368	56.7	1.683	50.6	.704
17	60.0	.968	62.8	.517	48.0	1.209	56.3	.246
18	62.4	- .791	64.1	- .394	55.6	-1.289	55.0	-1.577
19	61.8	- .802	64.6	- .505	54.6	-1.062	59.6	- .448
20	45.6	4.238	47.1	4.496	47.0	3.204	45.5	2.648
22	61.9	2.083	65.0	1.404	56.7	4.542	60.1	1.721
23	66.1	.058	64.5	- .518	60.0	-1.177	63.0	.068
24	57.9	5.601	57.6	6.516	45.5	6.359	50.4	5.699
25	69.8	-2.597	74.6	-2.535	58.5	-2.351	72.4	-1.895
26	63.6	-1.293	65.4	- .512	50.5	- .979	57.1	-1.534
28	72.2	-2.269	75.1	-2.196	56.4	-2.395	72.1	-1.766
29	71.1	-1.685	74.0	-1.721	61.8	-1.228	65.3	- .972
30	71.9	-3.290	73.5	-3.271	65.1	-2.883	69.2	-1.790

---

[1] See Table 8 for stream names and locations of water quality monitoring stations.

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Table 39

[illegible]

[illegible]

[illegible]	[illegible]	Constant	[illegible]	[illegible]	[illegible]	Conductivity at 25°C	CO_2	[illegible]	Nitrates	[illegible]	Chlorides	Hardness	Color	TDS	SO_4	Coliform Bacteria	[illegible]
1 [illegible]	[illegible]	.574			.4[illegible]					1.503							
2 [illegible]	[illegible]	.209											.035				
3 [illegible]	[illegible]	3.9[illegible]															-.010
4 [illegible]	[illegible]	[illegible]														.001	
5 [illegible] Use Index	[illegible]	2.0[illegible]		.075							-.017						
6 [illegible] Fishing	.4049	-.5[illegible]			.3[illegible]							-.002					.012
7 Wading	.23[illegible]	-.5[illegible]		.036													.01[illegible]
8 Picnicking	[illegible]	.317		.034			-.019										
9 Sitting	.37[illegible]		-.2[illegible]	.036	.110		-.019										
10 Games	---																
11 Walking	.3[illegible]	.495		.055	.098						-.005						
12 Bird watching	.4[illegible]	.7[illegible]														-.001	
13 Skating	[illegible]	.85[illegible]	-.25[illegible]	.0[illegible]					-.035						.004		
14 Other	----																
15 [illegible] Fishing	.4066	-1.[illegible]		.078		-.001		.185	-.034								
16 Wading	.3[illegible]	-.045	-.151	.047													.018
17 Picnicking	.3[illegible]	.265												-.001			
18 Sitting	.2[illegible]	.115	-.234	.031	.104												.012
19 Games	.1423	.257	-.07[illegible]														
20 Walking	.2763	.465		.052							-.004						
21 Bird watching	.1292	.292														.001	
22 Skating	.18[illegible]	.15[illegible]	-.194	.047									-.003				
23 Other	.2265	.010		.002													
24 Total Activities Engaged in	.3324	4.759	-.944	.36[illegible]						-3.217							
25 Want to live Closer	.2034	.259	.132												-.002		
26 Want to live Farther	----																
27 [illegible] more	.2793	.936	.251							-.355							
28 [illegible] near stream worth more	.2759	.762									-.009						
29 Pay more tax to clean stream	.2873	-.063										.002					
30 [illegible] much more tax ($)	----											-.003					
31 Environmental Concern Index	.1098	2.221		-.087													

N = 303 All listed coefficients significant at the 0.05 level. Underlined coefficients significant at the 0.01 level.

* In addition to the independent variables listed, the following were tested for each dependent variable and found not significant: Dissolved oxygen (percent saturated), total alkalinity, phosphates as PO_4, turbidity, loss on ignition.

phenomenon by determining the common relationships among the variables available to describe it [Rummel, 1967]. Thus, the underlying patterns among the 16 chemical indicators were deduced and identified as a number of basic characteristics or components.

For this analysis, the annual average, median, second worst, and July chemical measurements were analyzed separately. The fact that many of the chemical indicators "move together" is indicated by the fact that the first principal component accounted for roughly half of the variance of all the chemical indicators (Table 40). The first four components taken together account for about 80% of the variance, and the first five taken together account for about 90%.

The loadings, listed on Table 40, indicate that nearly all chemical variables are correlated moderately strongly with the first principal component. Only pH, nitrates, and turbidity--and to a lesser extent color and alkalinity--are not represented strongly on this component.

Because the first principal component accounts for such a major proportion of the variance in the individual chemical variables, it was considered suitable for use as a summary variable measuring water quality. Scores for each of the stream sites on the first component are given in Table 38. The streams with the highest scores have the worst pollution (or the lowest water quality). It must be kept in mind, in considering these scores, that the first principal component involves a weighting of chemicals only on the basis of the extent to which each chemical is correlated with the others, not on the basis of which chemicals are judged to be most critical to "water quality." The collection of component scores must be viewed in somewhat the same way as one would view a simple average of (standardized)chemical concentrations, in that both are free of subjective factors.

Correlations between these scores and the variables expressing perception, usefulness, and use are given in Table 41. It will be seen that although the correlations with the Water Quality Index are higher for some variables than the correlations with the first component, a substantially greater number of significant correlations occur with the first component.

a_j (j = 1 ... 16) are the regression coefficients corresponding to the 16 separate chemical indicators of water quality.

Distance to stream, measured as the shortest straight-line distance, was put in logarithmic form so that a given increment in distance would have less effect for residents far away from the stream than for residents close to the stream. Size of drainage area of the stream, which has direct implications for the size and character of the stream itself, was also expressed in logarithmic form, since an increase in drainage area from, say, one to two square miles would have a much greater effect on perceptions than an increase from 11 to 12 square miles.

The results of this regression analysis are given in Table 39. They indicate that the higher water quality actually is: the less the stream appears to the residents to be polluted, the better opinion they have of its general attractiveness, the more suitable they consider it for nearly all activities listed, and the more they engage in those activities. The respondents' desire to live closer to the stream and their belief that their own houses and houses right next to the stream are worth more because of the stream, also tend to be stronger if the stream's water is cleaner.

In most of the equations of Table 39, number of children is significant, and in many of them the log of distance between stream and residence is significant. Generally, at least one chemical variable is significant in each equation, with a wide variety of chemicals appearing in the various equations. The summary Water Quality Index is significant in 5 equations--in more equations than any single chemical. However, the Water Quality Index falls short of acting as a general indicator of water quality which provides explanation of most of the variables concerning perception and use of streams. The potential value of such a general indicator in summarizing and communicating results has already been mentioned.

Summary Indicators of Chemical Water Quality

In an attempt to derive a suitable summary measure, the principal components were computed for the set of 16 chemical indicators. The object of principal component analysis is to identify the major underlying characteristics of a given

Table 41

SIGNIFICANT CORRELATIONS BETWEEN SUMMARY MEASURES OF WATER QUALITY AND VARIABLES EXPRESSING PERCEPTION, USEFULNESS AND USE OF STREAM SITES

		Scores on First Component of Pollution				Water Quality Index			
		Year Average	Median	Second Worst	July	Year Average	Median	Second Worst	July
1	Perceived Pollution	.29	.28	.27	.28	-.23	-.25	-.24	-.23
2	Trash Pollution								
3	Sum of Pollution	.24	.27	.25	.27	-.26	-.24	-.26	-.25
4	Don't visit: too polluted		.15	.14	.14				
5	Attractiveness Index	-.39	-.39	-.35	-.33	.24	.27	.17	.24
6	Good for Fishing	-.28	-.29	-.27	-.28	.22	.26	.24	.29
7	Wading	-.24	-.24	-.26	-.24	.29	.25	.28	.30
8	Picnicking	-.25	-.26	-.28	-.27	.23	.23	.16	.23
9	Sitting	-.27	-.28	-.27	-.25	.20	.18	.15	.20
10	Games								
11	Walking	-.22	-.25	-.21	-.22	.13	.13		
12	Bird Watching	-.18	-.23	-.20	-.21				
13	Skating	-.16	.15	.13	.13		-.18		
14	Other								
15	Engage in Fishing	-.21	-.18	-.13	-.17	.14	.12		.13
16	Wading	-.19	-.17	-.20	-.18	.24	.22	.21	.25
17	Picnicking		.14		-.12				
18	Sitting	-.26	-.28	.30	-.29	.27	.25	.17	.26
19	Games								
20	Walking	-.18	-.20	.15	-.16				
21	Bird Watching	-.13	-.18	-.16	-.17	.11			.11
22	Skating								
23	Other								
24	Total Activities Engaged in	-.25	-.26	-.25	-.25	.20	.18	.13	.21
25	Want to live Closer								
26	" " " Farther								
27	House value more	-.19	-.21	-.21	-.22	.16	.14		.14
28	Houses near stream worth more	-.20	-.24	-.18	-.20				

All correlations listed are significant at the 0.05 level; underlined correlations are significant at the 0.01 level.

Table 40

FACTOR LOADINGS ON FIRST COMPONENT OF POLLUTION

	Year Average	Median	Second Worst	July
Coliform Bacteria	.246	.267	.150	.238
Conductivity at 25°C	.317	.309	.347	.328
Dissolved Oxygen (% sat.)	-.263	-.268	-.132	-.208
CO_2	.270	.244	.266	.322
Alkalinity	.288	.291	.182	.051
pH	.110	-.059	-.186	-.107
Nitrates	.127	.034	.094	.038
Nitrites	.299	.265	.299	.298
Phosphates	.133	.305	.231	.341
Chlorides	.303	.301	.342	.346
Turbidity	.032	.151	-.057	-.008
Hardness	.271	.265	.326	.255
Color	.254	.265	.122	.053
Total Dissolved Solids	.322	.290	.352	.344
Loss on Ignition	.261	.210	.307	.248
SO_4	.276	.261	.299	.319
% total Variance explained				
by first component	.57	.61	.47	.47
by components 1-4	84	86	80	77
by components 1-5	90	90	87	83

This is especially true for the variables describing what activities the stream is considered good for (variables 6-14), and what activities are actually engaged in (variables 15-24). The correlation results using the first component are also more satisfying than those reported in Table 39 in that they indicate that the more polluted a stream is, the less residents think that houses bordering on it would be worth more because of their closeness to the stream.

(Note: As can be seen from Table 38, a few streams have extremely high scores on the first component. In order to eliminate the possibility that these scores would dominate the correlations, all scores larger than 3.0 were assumed to be 3.0 and a second set of correlations were run. The correlations of this set were generally slightly lower than those presented in Table 41, which is based on the factor scores as given in Table 40.)

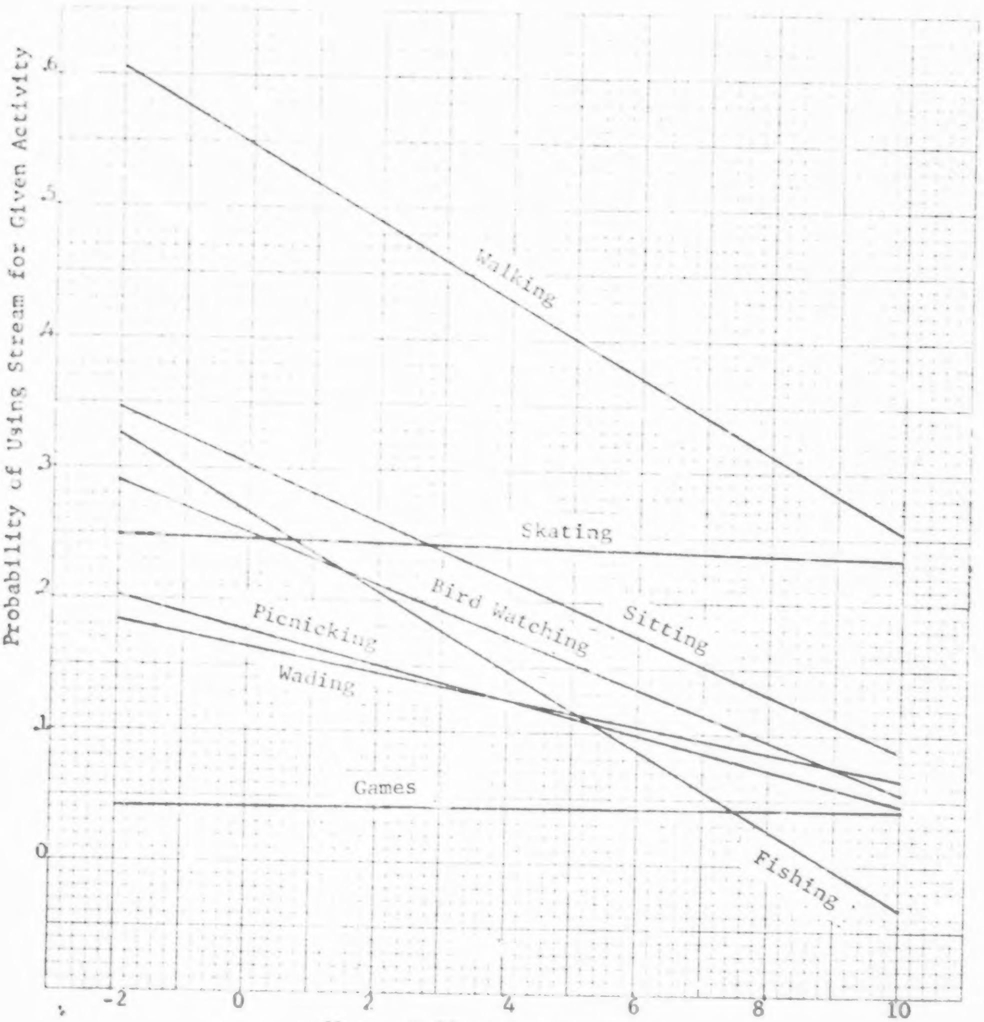
Of the four sets of data used for computing the first component, the set comprised of year-average measurements provides the highest levels of correlation with the dependent variables. Therefore, the correlations of the first component based on the year averages are used to derive curves expressing how pollution level is related to each of the dependent variables of the average individual in the sample. (The average individual is one who has 1.53 children and lives a distance of 813 feet from the stream, which has a drainage area of 18.2 square miles.)

Curves relating to use of stream site are presented in Figure 13. Curves relating to perception of pollution, attractiveness, and effect on house value are given in Figure 14.

The probability of using a stream site falls with increase in water pollution for nearly all activities. Thus the probability of wading and fishing, for which the relevance of water pollution is direct, and of walking, sitting, bird watching, and picnicking, for which water pollution is relevant through its effects on aesthetics, all fall at a roughly similar rate with increasing water pollution. The two activities which do not fall with increasing water pollution are ice skating and playing ball or other games. One would not expect water pollution to have much effect on these activities, instead

Figure 13

EFFECT OF WATER POLLUTION ON
USE OF STREAM SITES



their major determinant is the availability of the necessary physical facilities--smooth and solid ice for skating, and the appropriate playing field for ball and other games.

Water pollution as perceived by the residents is consistent with water pollution as measured by chemical analysis (first two graphs of Figure 14). On average, the residents considered the streams in our sample with the worst water quality to be "somewhat polluted." This perception can be compared roughly with measurements using the Water Quality Index, which ranges from low water quality (or very polluted): 0, to high water quality (not at all polluted), 100. The worst streams in our sample had Water Quality Indexes of 45-55, which would appear to fall in the category of somewhat polluted, although the developers of the Water Quality Index do not interpret their numerical indices in qualitative terms. The best streams in our sample had Water Quality Indices of around 75, and were judged to be "a little polluted" by the respondents.

The attractiveness rating given to the stretch of stream is related to the level of water pollution, the most badly polluted streams being judged on average to be somewhat unattractive and the least polluted to be somewhat attractive. There is a corresponding result with regard to the perceived value of real estate. Houses near streams with good water quality are perceived as being worth between "a little more" and "much more" because of their closeness to the stream. On the other hand, even houses bordering the most polluted streams in the sample are considered to be worth "a little more" because of their closeness to the stream. People are probably somewhat more reluctant to make statements about the value of their own houses than about the value of other people's houses. Thus, the probability of believing that one's house is worth more because of the closeness of the stream is only 0.2 for the cleanest streams in the sample, and 0.025 for the dirtiest. However, the relationship is clear: higher water quality is perceived as having a positive effect on house value.

CONCLUSIONS

This study has made it possible to fit specific curves to the relationships hypothesized generally in Figure 10. In general,

Figure 14

EFFECT OF WATER POLLUTION ON PERCEPTION OF STREAM AND HOUSE VALUE

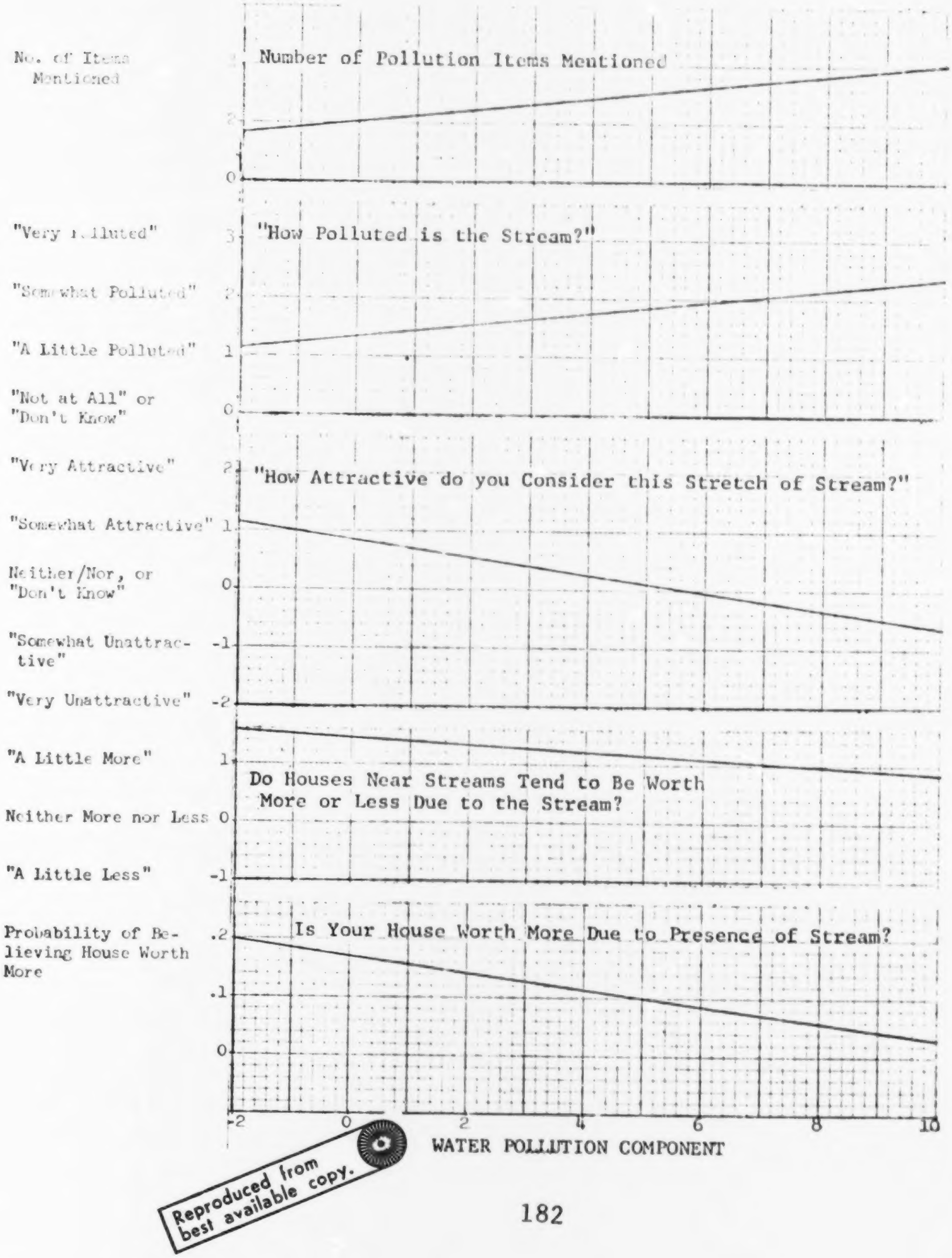


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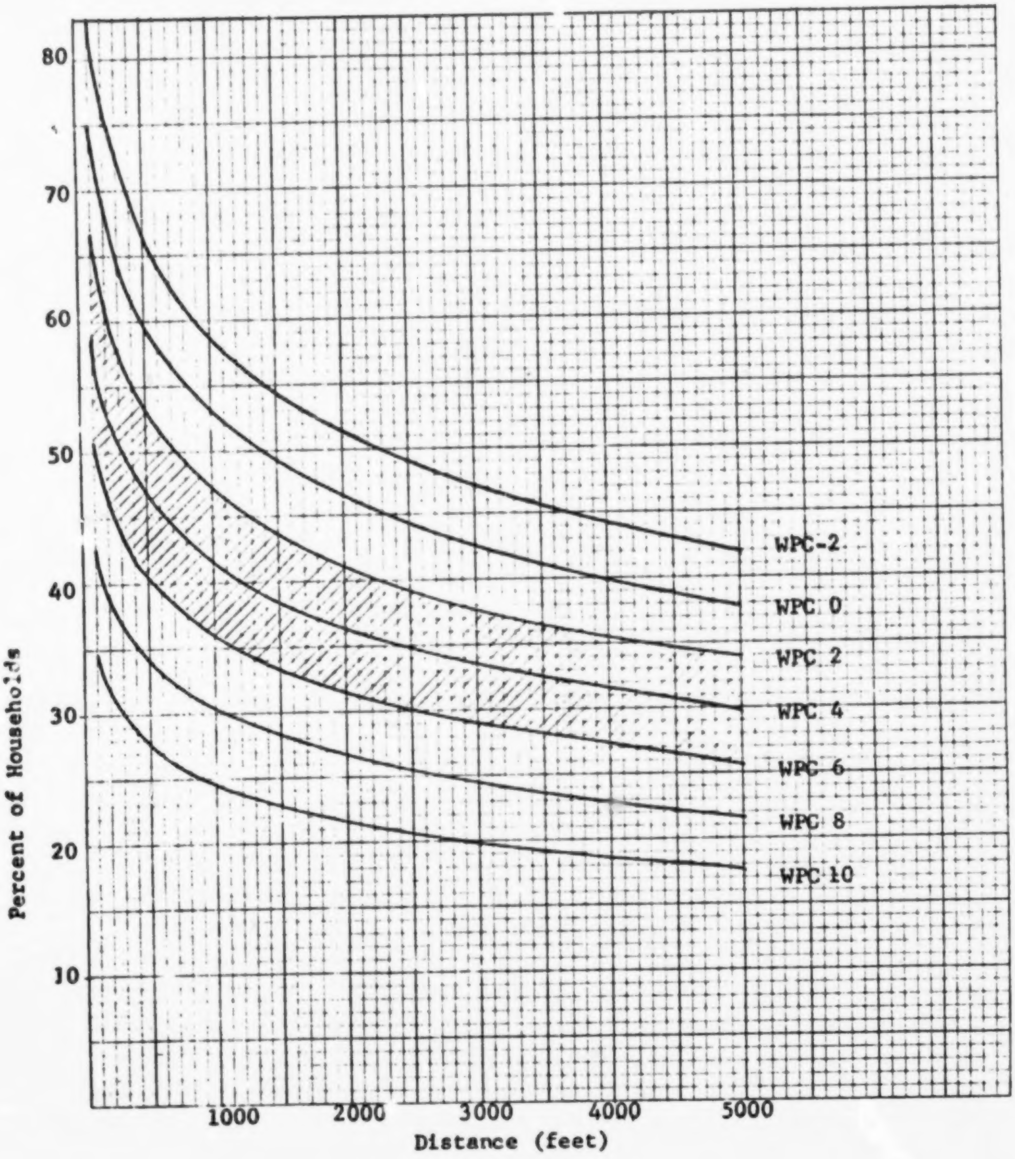
Figure 15

EFFECT OF WATER POLLUTION AND DISTANCE TO RESIDENCE ON PER CENT OF HOUSEHOLDS WHICH USE STREAM FOR TAKING A WALK



the empirical work has borne out the hypothesized relationships: actual use and perceived suitability for use of a stream, and perceived land values near the stream, are greater if the stream water is cleaner, and greater for nearby residents than for those living at greater distances.

In Figure 15, two of these relationships have been brought together in a single graph which shows how the probability that a resident will use a stream site for taking a walk varies with the distance of his home from the stream and with the water quality of the stream. (This graph--and the graph of Figure 16--was prepared by combining the information on the relationship between use and distance from Table 36 and the information on the relationship between use and water pollution from Figure 13.)

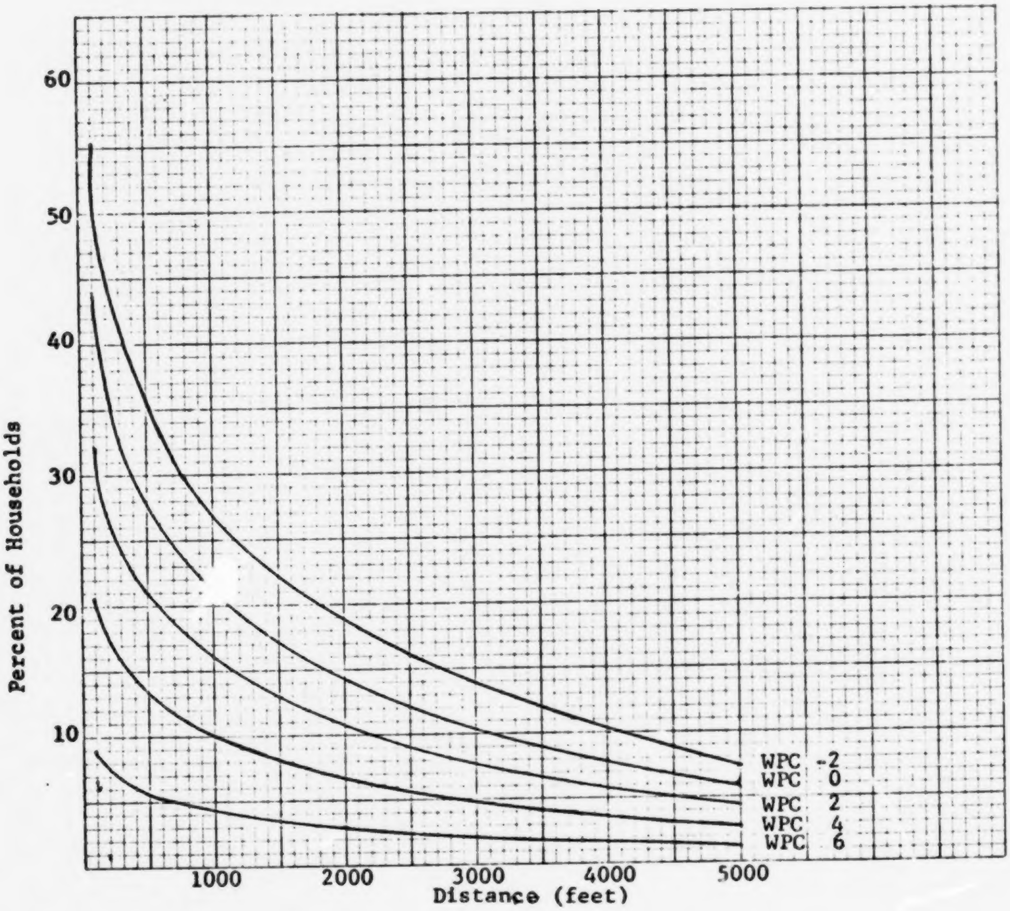
Take, for example, a resident who lives 1,000 feet from a stream whose score on the first component of pollution is 6. The probability is 36% that he actually uses the stream site to take a walk. Consider what would happen if a pollution abatement program were undertaken with the result that the score of the stream on the first component of pollution was lowered to 2. Under those conditions the probability that the typical resident at 1,000 feet would walk at the stream site would be raised to 47%. This is an increase of 11%, which results in about one-third more use than would have been enjoyed before the abatement program.

The increase in probability that the total resident population would use the stream site for walking is also indicated by Figure 15, on the assumption that the density of settlement does not vary with distance from the stream. In that case, the total increase in probability is indicated by the shaded area on the figure. This increase may be related to the total probability before the change in water quality, which is given by the area beneath curve WPC 6.

A second approach to increasing the benefits derived from the stream would be to increase the density of settlement near the stream. The effect of such a change in density of settlement (and any variation in density) on the total probability of using the stream for walking could be determined by weighting the curve by the density found at each distance.

Figure 16

EFFECT OF WATER POLLUTION AND DISTANCE TO RESIDENCE ON PERCENT OF HOUSEHOLDS WHICH ENGAGE IN A TYPICAL ACTIVITY (SUCH AS SITTING OR WADING) AT STREAM



The effects of combinations of changes in water quality and density of settlement can be explored using Figure 15 for walking or Figure 16, which is more typical of all of the activities given earlier in Figure 11.

VII. EVALUATION OF EFFECTS: CAPITALIZATION OF EFFECTS OF ENVIRONMENTAL PRESERVATION IN LAND VALUES

The previous chapter was concerned with the evaluation of the range of fiscal and non-fiscal benefits which result from stream valley preservation. Nearly all of these effects, and especially the non-fiscal or environmental benefits, can be expected to be registered in higher land values. This increase in value is enjoyed directly by landowners, who themselves constitute a significant proportion of the public, and secondly by the general public through higher property tax revenues.

THE EXPRESSION OF ENVIRONMENTAL BENEFITS IN LAND VALUES

It is worthwhile to consider at a general level the manner in which environmental benefits may be translated into land values. Basically, differential land values are created as a result of the importance of distance to an environmental amenity or other facility. Persons residing near the area in question are more easily able to derive benefits from its existence than persons living farther away. Presumably, there is some distance beyond which persons derive virtually no benefit at all. Assuming that persons recognize the value of living close to the amenity, the price or rent of land close to the amenity should be bid up above what it would otherwise be. The amount that it is bid up comprises a location rent similar to the rent on a larger scale associated with proximity to a large city.

At a theoretical level, a case can be made that most or all people-oriented value-related effects created by an environmental amenity will be expressed in terms of "location rent." Given that the critical factor is distance, and that distance is determined by residential location utilizing some minimum amount of land, then market forces should cause land value at each point to be bid up by an amount just equal to the environmental benefits obtained at that point. This location rent would be measurable as the difference, all else being equal, between the land price or rent at a given point where some benefits can be enjoyed and its price at distances greater than that at which any benefits at all can be enjoyed.

This analysis assumes that environmental features which yield benefits such as discussed here are not a free-good in an economic sense, that is, they are not ubiquitous and are not perceived as ubiquitous. The scarcity of environmental amenities is becoming increasingly obvious, at least in urbanized areas.

In order for a location rent gradient to be created in association with some amenity, the following must be true of at least a portion of persons in the market for housing:

1) Persons considering a residential site near some amenity must be able to imagine what use and enjoyment they would derive from the amenity by living there.
2) Persons must be willing to attach, at least implicitly, a money value to this use and enjoyment. This implies that persons recognize that environmental amenities are in scarce supply.

Two research efforts concerning land value effects will be reported in this chapter. The first is concerned with devising a statistical model which would make it possible to estimate the market value of a parcel of land given information on its characteristics, the characteristics of its neighborhood, and its distance from certain amenities and population centers. The second effort is concerned with estimating the effects on nearby land values of a large urban park.

THE DETERMINANTS OF LAND VALUES

The effects of environmental characteristics, and their preservation, upon land values are not immediately evident, since many factors affect land value. Therefore, if these effects are to be identified, it is necessary to design a statistical model which includes as variables all the major factors which affect land prices. Research was carried out for the purpose of constructing such a model [Coughlin and Fritz, 1971]. This research, which is summarized here, has the ultimate purpose of providing a tool for estimating the effect of a conservation easement program on land values. With this ultimate purpose in mind, data were gathered on sales of unimproved parcels located in the watershed of the Upper East Branch of the Brandywine Creek in Chester County, Pennsylvania. Extensive plans involving the purchase of conservation easements were developed for this watershed in 1967-1968 [Institute for Environmental Studies, et al.], but were not carried out [Keene and Strong, 1970; Leopold, 1970; Thompson, 1969]. Therefore, the ultimate purpose of measuring the effect of conservation easements on land values could not be achieved through the study.

Research Procedure

The 37-square-mile watershed of the Upper East Branch of the Brandywine, from which data on sales of unimproved parcels were gathered, lies about 35 miles from the center of Philadelphia, and about 25 miles from Wilmington. Thus, it is beyond the area of present suburban expansion and only now is beginning to experience the growth of an exurban population. In 1950, the watershed had about 67 persons per square mile; by 1966 the population density had grown to only 100 persons per square mile.

Unimproved (that is, undeveloped) parcels were studied in order to avoid the difficult problem of estimating and adjusting for the value of buildings and other structures which are found on improved or developed land.

Of the total number of sales recorded, many could not be included in the analysis because they obviously did not reflect market prices. A limited number of other transactions had to be eliminated from the analysis because a complete set of data was lacking (e.g., price, size of parcel, or location of parcel was not available). The resulting sample which was analyzed consisted of 106 transactions.

The variables measured for each of the parcels are identified in Table 42 and their means and standard deviations are listed in Table 43. The dependent variable is price per acre. The independent variables include those which describe the characteristics of the parcel itself (its size, its limitations for sewage disposal, its use, its slope, and whether or not it includes a stream), characteristics of the parcel and its surrounding area (residential density of neighborhood and roughness of land), the accessibility of the parcel to urban activities and services and to natural amenities (distance

Table 42

VARIABLES USED IN ANALYSIS OF SALES OF UNDEVELOPED PARCELS

DEPENDENT VARIABLE

X_1 price per acre (data from Chester County Assessor's Office)

INDEPENDENT VARIABLES

Variables Measuring Characteristics of Parcel

X_2 size of parcel (acres)

X_3 percent of land having only slight or no limitations for on-site sewage disposal

X_4 percent of land having moderate limitations for on-site sewage disposal

X_5 percent of land having severe limitations for on-site sewage disposal

X_6 soils limitation index $2(X_5) + X_4$

(Data for X_3-X_6 from U.S. Soil Conservation Service, Soil Survey-Chester and Delaware Counties, Pennsylvania, 1963).

X_7 percent of land in Flood Plain District (measured from map 27, Plan and Program for the Brandywine).

X_8 percent of land in Stream Buffer District (measured from map 27, Plan and Program for the Brandywine).

X_9 percent of land in Woods and Slopes District (measured from map 27, Plan and Program for the Brandywine).

X_{10} percent of land in forestry and pasture (measured from map prepared by RSRI staff)

Table 42- Cont.

VARIABLES USED IN ANALYSIS OF SALES OF UNDEVELOPED PARCELS

X_{11}	percent of land in farming (measured from map prepared by RSRI staff)
X_{12}	percent of parcel wooded (measured from U.S. Geological Survey Map).
X_{13}	average slope of land in parcel (horizontal distance for 20' change in elevation; measured from U.S. Geological Survey Map).
X_{14}	feet of road frontage per acre (total number of front feet divided by acreage)
X_{15}	existence of stream on parcel (0, 1)
X_{16}	existence of road frontage on parcel (0, 1)
X_{17}	residential density of neighborhood (number of dwellings in 1 square mile square centered on parcel)
X_{18}	maximum slope of land in immediate neighborhood (larger of N-S or E-W slope over 2600 feet centered on parcel)
X_{19}	roughness of land (standard deviation of 25 elevation measurements equally spaced over 1 mile square centered on parcel)
X_{20}	roughness of land (approximation of surface area of 1 square mile of land centered on parcel).

Variables Measuring Accessibility of Parcel

X_{21}	distance to King of Prussia industrial and shopping centers (miles)
X_{22}	accessibility to manufacturing employment in surrounding locations weighted by distance squared:

Table 42- Cont.

VARIABLES USED IN ANALYSIS OF SALES OF UNDEVELOPED PARCELS

$\sum_j \frac{E_j^t}{d_{ij}^2}$

E_j^t = manufacturing employment at location j in year of land sale, t. (Locations are Coatesville, Downingtown, Honey Brook, Pottstown, Phoenixville)

d_{ij} - distance along highways from parcel i to town location j

X_{23} accessibility to manufacturing employment in surrounding locations weighted by distance:

$$\sum_j \frac{E_j^t}{d_{ij}}$$

X_{24} distance to nearest elementary or secondary school (miles)

X_{25} distance to nearest perennial stream

X_{26} distance to nearest major road (route 322 in all cases).

Variable Expressing Characteristic of Township

X_{27} Property tax rate on market value of property. (Source: Table IX, Local Government Financial Statistics, Department of Internal Affairs, Commonwealth of Pennsylvania).

Variable Expressing Date of Sale

X_{28} year of sale (1962 = 1, 1963 = 2, ... 1968 = 7).

Table 43

MEANS AND STANDARD DEVIATIONS OF VARIABLES

Variable & Units		Parcels under 3 Acres		Parcels of 3 Acres or More		All Parcels	
		Mean	S.D.	Mean	S.D.	Mean	S.D.
Dependent Variable							
X_1	\$/acre	1,287.40	740.33	628.04	416.43	1,019.92	706.26
Independent Variables							
X_2	acres	1.28	0.72	17.77	19.28	7.97	14.67
X_3	%	14.29	34.11	6.16	18.02	10.99	28.86
X_4	%	47.94	45.47	43.58	35.53	46.17	41.60
X_5	%	37.78	42.89	48.05	34.28	41.94	39.77
X_6	index	123.49	62.76	139.67	44.25	130.06	56.32
X_7	%	1.59	12.60	14.09	30.43	6.66	22.41
X_8	%	17.30	35.11	18.77	26.26	17.90	31.69
X_9	%	22.22	40.25	20.47	35.99	21.51	38.41
X_{10}	%	37.30	48.33	55.12	46.39	44.53	48.14
X_{11}	%	31.83	45.83	44.65	46.13	37.03	46.17
X_{12}	%	29.06	44.48	37.44	41.25	32.46	43.20
X_{13}	%	0.748	5.79	9.40	5.37	8.26	5.68
X_{14}	ft/ac.	160.97	193.57	45.09	42.62	113.96	161.62
X_{15}	0,1	0.048	0.215	0.302	0.465	0.151	0.360
X_{16}	0,1	0.778	0.419	0.744	0.441	0.764	0.427
X_{17}	DU/sq.mi	46.65	30.09	23.05	13.36	37.075	27.235
X_{18}	%	3.50	2.02	4.14	2.68	3.76	2.32
X_{19}	ft.	53.50	22.56	69.47	31.47	59.98	27.54
X_{20}	ft.	52,050.27	46.75	52,082.98	65.39	52,063.40	57.16
X_{21}	mi.	27.10	2.82	29.54	4.12	28.09	3.59
X_{22}	empl x d^{-2}	3,202.64	516.90	2,818.13	421.03	3,046.65	514.44
X_{23}	empl x d^{-1}	370.23	236.76	249.28	109.13	321.16	203.53
X_{24}	mi.	2.75	1.45	2.99	1.53	2.85	1.48
X_{25}	ft.	1,119.10	769.27	975.84	971.37	1,060.98	858.21
X_{26}	ft.	8,011.14	5,761.16	13,639.60	7,867.59	10,294.39	7,215.86
X_{27}	mills	1.041	0.655	1.037	0.270	1.040	0.531
X_{28}	1,...7	5.86	1.50	5.77	1.76	5.82	1.60

along radial expressway to King of Prussia industrial area and shopping center, distance to nearest elementary school, generalized accessibility to manufacturing employment, and distance to nearest stream), and a variable characterizing the township in which each parcel is located (tax rate on market value). The final variable is year of sale.

Availability of public water and sewer does not appear because virtually none of the land in the watershed is yet supplied with these services. Zoning classification of the land is not included either, since zoning ordinances were not passed in any of the townships until the latter part of the period for which sales data were collected. In 1968, three out of six townships still did not have zoning ordinances. Therefore, it was judged that zoning probably was not an important consideration for most sales in the sample.

As can be seen in Table 42, the characteristics are rather general ones and refer to topography, vegetative cover, and land use. In addition to scenic amenity, these characteristics also relate to ease of development. Unfortunately, many of the characteristics implying enhanced scenic value (which should enhance sales price) also imply difficulty of development (which should reduce sales price). For example, a parcel which consists largely of flood plain or woods, or has steep slopes, is likely to be quite scenic, but it is also likely to be difficult and expensive to develop. Therefore, it is difficult to predict how the market will price such a parcel. As long as major subdividers are not operating in the area, it is possible that the parcel will have a relatively high price because of its scenic quality. But as soon as cost-conscious developers appear, other less scenic but more readily buildable land may bring a relatively higher price.

General Results

Earlier analysis [IES, RSRI, and USGS, 1968], as well as discussion with appraisers and general knowledge of the real estate market, has indicated that the market for building lots is distinct from that for large tracts. In general, it is believed that the price per acre for land in large tracts is substantially lower than for land in small building lots. Therefore, before beginning the analysis, the sample of transactions was divided into those for parcels of less than 3 acres and those for parcels of 3 acres or more.

Table 44

SUMMARY OF REGRESSION RESULTS

(Dependent Variable: Sale Price Per Acre)

	Parcels under 3 Acres		Parcels of 3 Acres or More		All Parcels	
Multiple R	.668		.709		.751	
Std. error of estimate	564.76		308.93		477.66	
No. of observations	63		43		106	
Constant Term	834.54		1,884.92		497.06	
Independent Variables	Coef-ficient	t-Statistic	Coef-ficient	t-Statistic	Coef-ficient	t-Statistic
Characteristics of Parcel						
2. Parcel size					-6.46	-1.9
7. % slight limitations for on-site sewage					3.95	2.3
12. % parcel wooded	-5.04	-3.1	-3.05	-2.0	-3.19	-2.7
14. road frontage per acre					0.82	2.6
15. stream on property	-793.18	-2.3				
Characteristics of Neighborhood						
17. residential density	13.66	5.6			14.59	7.57
19. roughness of land			-5.89	-2.4		
Accessibility of Parcel						
21. dist. to King of Prussia			-28.00	-2.1		
26. dist. to nearest stream			0.10	1.4		

Stepwise regression analysis was carried out both for the subsets of small and large parcels considered individually, and also for the entire set of transactions. The results are summarized in Table 44. The equations and their individual component variables were generally significant at the 0.05 level. All variables appear with the expected sign, with the possible exception of those variables relating to streams (variable 15 for small parcels and variable 25 for large parcels). Given the view that a stream is an amenity, one might hypothesize that the presence of a stream would add to property value. However, for both large and small properties, accessibility to a stream was found to be associated with lower land values. The reason for this is understandable for small properties: the existence of a stream on a property of less than 3 acres implies that at least a significant proportion, if not all, of the property is in flood plain, marsh, or is steeply sloped. It is less clear why the price of large parcels should be affected adversely by stream accessibility, since even if a stream crossed the parcel, most of the land in the parcel would remain buildable. At any rate, the effect for large parcels is weak and the coefficient fails to attain statistical significance. Neither "stream"variable appears in the equation for the combined sample of large and small parcels combined.

The results for large and small properties indicate that value probably is determined differently for each group. Only one variable--percent wooded--appears consistently and significantly for each sub-group and for the entire sample. The stream variables appear consistently, if not always significantly, for the two sub-groups. In addition to these variables, the price per acre of small parcels is influenced by density of residential development in the neighborhood. Increased density of residential development in the neighborhood implies the existence of certain urban services in addition to proximity of neighbors--which is especially important to families new to the area desiring playmates for their children. Therefore, although it is hypothesized that many people move into the Upper East Branch Brandywine area because they are attracted to the natural countryside, the availability of neighbors is also a consideration, especially for those who buy relatively small lots, which are more characteristic of suburban development than of rural development.

For large parcels, a different set of variables came into the regression equation: distance to King of Prussia commercial and industrial area (which is a proxy for distance to the center of the metropolitan area) and topographic roughness of the neighborhood. Both of these variables can be interpreted as measures of the development potential of the land, and their presence in the regression equation suggests that large tracts are being bought with an eye to their eventual development. An alternative interpretation of topographic roughness is that it is a measure of amenity, rolling or hilly land being more desirable than flat land. However, to be consistent with such an explanation, topographic roughness would have to appear with a positive sign in the equation.

Although the prices of large and small parcels appear to be determined by different sets of variables, the best overall statistical explanation is achieved when parcels of all sizes are combined. Multiple R increases to .75 at the same time that the sample size is approximately doubled, resulting in a substantial increase in level of significance. In the equation for the combined sample, parcel size appears as an independent variable, reflecting the different market forces acting on large and small parcels. Residential density, which appeared in the equation for small parcels, also appears in the equation for all parcels. In addition, frontage per acre and percent of land with slight limitations for on-site sewage appear in the combined equation. These variables would have been the next to enter in the stepwise regression analysis of small parcels. However, missing from the combined equations are: topographic roughness, distance to King of Prussia, and distance to nearest stream, all of which appeared in the equation for large properties, and existence of a stream on the parcel, which appeared for small parcels.

In that these variables do not appear in the combined equation, it is less appealing than the equations for sub-groups. The lack of distance to King of Prussia, or any other variable expressing accessibility, is particularly disappointing. However, there may be a reason to believe that differences in accessibility among locations in the Upper East Branch basin would have relatively little effect on price. The basin lies 17 miles from the King of Prussia Interchange and between 30 and 35 miles from the center of Philadelphia, and is well beyond the ring in which subdivision activity is now most intense. At such distances from major activity centers, an additional few miles is likely to have little effect on perceived distance and correspondingly little effect upon land price. Accessibility to nearby medium-sized urban centers (Downington, Coatesville, Honey Brook, Phoenixville and Pottstown), which is measured in variables 22 and 23, is quite strongly correlated with distance from King of Prussia. It is of interest that year of sale did not appear in the regression equation at a significant level. This indicates that the land market in the basin was not affected during the period by rapidly rising land prices, which typically precede urbanization. This is consistent with our interpretation of the distance-to-King-of-Prussia variable. If the zone of suburban development had reached the inner edge of the basin, one would expect to find a land price gradient dropping sharply with distance from King of Prussia and distance to the center of the metropolitan region.

The most significant independent variable explaining price per acre is residential density in the neighborhood. It appears at a far higher significance level than does any other variable in the small-parcel sample and in the complete sample. It does not appear, however, in the equation for large parcels, even though its correlation coefficient with price per acre is relatively high (0.496). This is evidently because residential density has a high negative correlation with roughness of land, which did enter the equation.

In summary, the equations for price per acre are statistically adequate, and consistent with the market, locational, and topographic conditions existing in the Upper East Branch Brandywine basin. The variables which appear in the equations should probably be considered in any attempt to construct a statistical model of the land market for any comparable area in the urban-rural fringe of a metropolitan area. However, in any such investigation it is likely that some of these variables would be found to be not-significant, while other variables, not in our equations, would be found to be significant. The equations derived here should be used as a guide for studies of other areas, but it would be improper to apply the equations as they stand to another area.

Results Specifically Concerning Environmental Attractiveness

The benefits of a land use and water resource plan, such as the Brandywine Plan, consist in part of "scenic" benefits. Following such a plan, certain areas would be selected in which urban development would be prevented. Thus, natural or semi-natural scenery would be retained for public enjoyment, even though the public could not actually enter on and use the land. An approximation of the value of the "scenery" provided by such a parcel of land is desired. Fundamental to an adequate approximation of the value of the "scenery" is the relationship between price per acre and variables which express certain aspects of environmental attractiveness.

In order to identify such relationships a number of "environmental attractiveness" variables were conceptualized and measured for the 28 properties which were sold in 1967 or 1968 and were still sufficiently undeveloped so that observations could be made in the field which would correspond, at least roughly, to observations which might have been made at the time of sale.

The conceptualization of the variables, which are listed in Table 45, is based on research on environmental perception and preference reported in Chapter V above. That research showed that a sample of middle-class suburban housewives preferred areas with a parklike landscape: generally open areas with low ground cover and a relatively small number of relatively large trees. Various aspects of this preferred landscape are measured in variables 1, 2, and 3. The view from a lot is generally considered to contribute to its desirability (variables 4 and 5). The hypothesized effect of the number of houses or mobile homes visible from the parcel (variable 6) is not clear, but our findings in the previous section concerning residential density would indicate a positive effect upon price per acre. However, residential density within sight of a parcel (i.e., variable 6) has only a very weak association with density within a one-mile square (correlation coefficient of -0.097 for all 28 properties). Therefore, it is reasonable to argue that number of houses visible and number of houses within an accessible distance have different functional and perceptual meanings for a prospective land buyer, and are not strongly associated as measures of physical density.

The last two variables listed in Table 45 are both at a somewhat higher level of abstraction and are measured less objectively than the earlier variables. The number of different elements or items observed by three field observers provides a measure of the "complexity" of a given landscape. (The resulting ratings have been adjusted for the systematic tendency of some observers to list more things than others.)

Table 45

CORRELATION COEFFICIENTS BETWEEN AESTHETIC VARIABLES AND SALE PRICE PER ACRE

Aesthetic Variable	Expected Sign	Less than 3 acres	3 Acres & over	All Trans- actions
1. Average girth of trees	+	-.560		-.322
2. Average height of ground cover (in.)	-	-.538	.343	-.306
3. Percent of area in open space	+	.346	-.615	.092
4. Log of length of longest view (ft.)	+	.028	-.137	-.144
5. Log of average length of view (ft.)	+	.086	-.199	-.134
6. Number of houses or mobile homes visible	-	-.046	.037	-.158
7. Average number of items observed	+	.293	-.201	.228
8. Average attractiveness rating (3 observers)	+	-.577	.171	-.485
Number of Transactions		18	10	28

Note: Correlations significant at the 0.05 level are underlined.

The attractiveness rating (variable 8) is a purely subjective rating (on a 1 to 5 scale) assigned by three observers and averaged.

Comparison of the expected sign of the correlation between each of these variables and sale price per acre with the signs of the actual correlations for our sample indicates few consistencies (Table 45). Although we hypothesized that environmental attractiveness should bear a positive relationship to land value, the majority of the correlations indicate a negative association. Only average height of ground cover, percent of land in open space, and average number of items observed have the expected sign both for the entire sample and for one of the sub-samples. Only one of these correlations--that involving average height of ground cover for small parcels--is significant at the 0.05 level.

In general, the level of significance of the coefficients is very low. The only coefficients significant at the 0.05 level for all transactions as a whole are those involving average girth of trees and the average attractiveness rating, and as was indicated above, these signs are in the opposite direction from that hypothesized. Because of the generally low significance levels of the environmental attractiveness variables, regression equations including them are not reported here. Suffice it to say that the only two such variables to enter the regression equations were: average number of items observed in the equation for large parcels, and average attractiveness rating in the equation for all parcels. Each of these appeared with a negative sign, indicating that the more attractive a parcel is, the cheaper it is.

We hesitate to draw any firm conclusions from our attempt to define and analyze variables describing environmental attractiveness, because of the small size of the sample of transactions. Our conclusions, also, are limited by the narrow range of variation in environmental attractiveness of the parcels in the sample, all of which are relatively attractive. Had our sample included parcels of breathtaking beauty or extreme ugliness, it is likely that the environmental variables would have been of greater statistical significance. However, our results are consistent with the apparently contradictory notion that land which is more scenic or attractive tends to be cheaper than land which is less attractive. Specifically, they suggest that a parcel which has large trees, or a large percent of its area in open space, or receives a high attractiveness rating is likely to sell at a lower price than other land.

Of these characteristics, the presence of large trees may add to the difficulty of development. The analysis in the earlier part of this paper also indicated that certain characteristics which suggest environmental attractiveness also suggest difficulty or expense of development and therefore are associated with lower prices per acre. As examples are the variables: percent of parcel wooded, topographic roughness of land, and existence of a stream on the parcel. Therefore, both parts of this analysis of land values indicate that environmental attractiveness, as we have defined it based upon our related research, has a negative association with land price. This association is not to be explained by saying that people do not like attractive land but by saying that they are more concerned with the fact that attractive land is generally more difficult or expensive to develop than flatter, less wooded land which is free of watercourses.

Since most of the land in the Upper East Branch watershed is undeveloped, and the parcels analyzed were all undeveloped, it is not possible to draw strong conclusions from this analysis and apply them to the question of the effect of a preserved stream valley and its open space upon nearby property values in urbanized areas. Environmental benefits conferred by such preservation are not perceived until urbanization begins. As urban development proceeds, and private open space disappears, the value of the preserved open space becomes more and more evident. The following study is more appropriate to such a situation. However, since it is concerned with only one open space, it does not include variables which describe the characteristics of open space, and therefore, is difficult to generalize from.

THE EFFECT OF A LARGE URBAN PARK ON REAL ESTATE VALUES

The household surveys reported in the last chapter indicate that a use gradient can be expected around an environmental amenity (see especially Figure 11). Associated with the benefit gradient one would expect to find a location rent gradient. (Although this study was not reported by FWQA, it is reported here because of its obvious relevance to estimating environmental benefits. The study was supported by the Public Health Service under Grant No. 1 R01 EM 00519-01.) The subject of this study was Pennypack Park, a 13,000 acre stream valley park in northeast Philadelphia. The area surrounding this park has been developed over the past twenty years--mostly with twin houses on 1/12 acre lots.

One of the major difficulties in identifying location rent lies in isolating of land value from the market value of property, which includes the value of buildings, utilities, and other structures on the land. Because much of the development around Pennypack Park was done at a large scale, relatively few basic house-types are represented. Therefore, it appeared possible to identify each house-type by a dummy variable, which would capture value of house and a base value of land, leaving the value of location rent to be explained by distance from the park.

A total of 16 house-types were identified from air photographs, field trips, and information in the Philadelphia Real Estate Directory. As an example, one house-type set consisted of houses which looked identical on the air photograph, were semi-detached with basement garage, had two stories, were of brick and frame construction, and were assessed at $9,200.

Such a house-type classification cannot reflect improvements which have been made to the inside of a standard builder's house and which are neither visible from the outside nor accounted for in the assessed value of the house. Obvious outside additions, such as swimming pools, were observed and such properties were dropped from the sample.

Dummy variables were also entered for year of sale, for whether or not the house was on an irregularly shaped lot, and for whether it abutted the park directly.

In order to eliminate influences other than the park, properties studied were limited to those which were closer to the park than to any other open space or did not adjoin any retail area or major highway. In addition, corner lots were excluded from the sample unless they bordered on the park, and these were identified specifically by dummy variables in the analysis.

The major focus of interest was on variables expressing distance to the park. Distance to the park was measured in two alternative ways: as the straight line from the house to the nearest point in the park, and as distance along public ways to the nearest point of public access to the park. The variables expressing distance were in the form of negative exponential functions of distance (to which a small constant had been added to prevent domination by small distances). Two different exponents, -1 and -2, were tested; -1 was found to be more satisfactory. The negative exponential gives a gradient asymptotic to the distance axis, which was considered a desirable property. The dependent variable (property value) was expressed in both log form and linear form, with similar regression results in each form. Only the linear form will be discussed here.

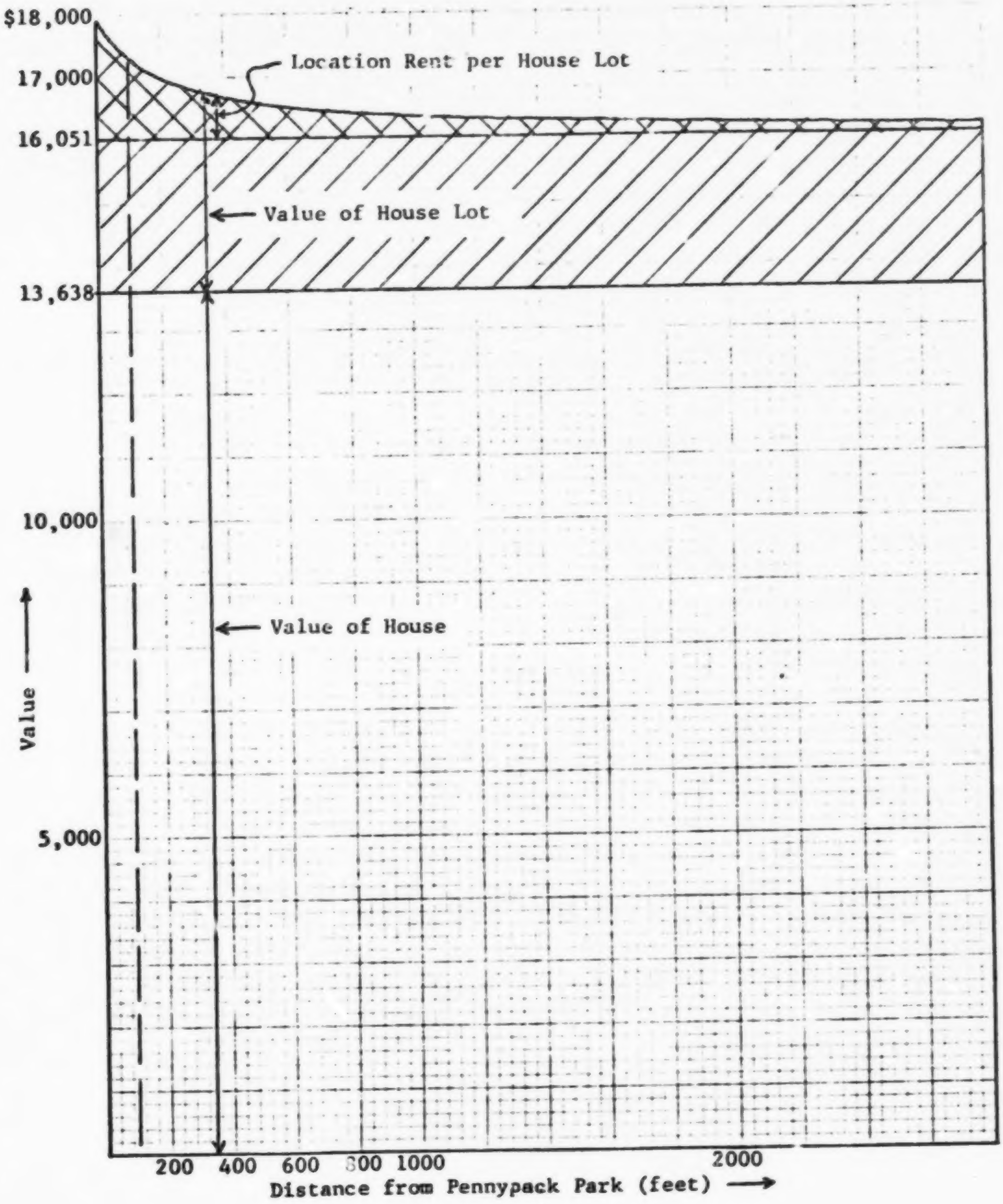
In the regression analysis the sale price for 303 properties was related to a set of independent variables consisting of one or more distance variables,and numerous dummy variables. The public access form of the distance variable proved to be the more significant form. The overall level of statistical explanation was quite high (multiple R = .902) but this was due primarily to the dummy variables. The distance variable was significant at the .05 level.

The magnitude of the estimated property value gradient can be appreciated from Figure 17. The location rent can be calculated as the difference between the estimated property value at a given distance and the "base" property value (i.e., the extrapolated value when distance from the park is infinite). The location rent gradient as estimated drops off rapidly with distance. The rent ranges from about $1,240 per property at 100 feet from the park to $138 per property at 2,500 feet from the park. At first glance, this amount does not appear to be very large. It is only 7.2% of total property price at 100 feet from the park, 1.9% at 1,000 feet, and 0.9% at 2,500 feet.

Location rent, however, must be considered in relation to land value, not to total property value. This is clear on a theoretical level, since the attribute of location is intrinsic only to land, not to the structures which may be built on it.

Figure 17

ESTIMATED VALUE OF RESIDENTIAL PROPERTIES BY DISTANCE FROM PENNYPACK PARK



By subtracting a rough estimate of average house price from total property price, land price may be identified. This was done by observing that for the entire sample the tax assessment of the house was 83.2% of total assessment. The value of the average property, $16,051, multiplied by 83.2%, yields the average house value of $13,638, which is plotted on Figure 17. The remaining distance under the curve represents land value, part of which is location rent. Relative to total land value, location rent due to the closeness of the park is substantial. At 100 feet it accounts for 34% of land value; at 1,000 feet for 11%, and at 2,500 feet for 5%. In dollars per acre--recall that on average there are 12 houses per acre--location rent due to the park falls from $15,000 at 100 feet to $1,700 at 2,500 feet. These values would appear to lie in an expected and reasonable range.

An estimate of aggregate value of location rent generated by Pennypack Park can be made by multiplying the values per dwelling unit found in Figure 17 by the numbers of dwellings found at corresponding distances. This computation yields a net increase in aggregate real estate value of $4,400,000 which is attributable to the park.

The results of this case study are indicative of what one might expect for a stream valley preservation project which involved retention of major areas of open space. However, they cannot be applied directly to such a project, since the estimating equations do not contain variables which explicitly measure characteristics of the retained open space and the developed area. A more general estimating equation, similar in scope to the equations developed in the previous section, would be necessary. Such an equation can be derived only by studying a large sample of open spaces and streams surrounded by built-up areas.

QUESTIONNAIRE FOR SURVEY RELATING TO THE EFFECT OF WATER QUALITY

Please answer all questions

Appendix to Chapter VI

This questionnaire is concerned with the stretch of ____________________ Creek near your home.

1.a) How familiar are you with this creek?

I know it very well	____
I know it fairly well	____
I know it is there, but that's about all I know about it	____
I didn't even know it was there	____

b) Do you consider this stretch of creek to be generally attractive or unattractive?

Very attractive	____
Somewhat attractive	____
Neither attractive nor unattractive	____
Somewhat unattractive	____
Very unattractive	____
No opinion	____

2. Are you usually aware of it when you drive by?

Yes ____

No ____

3.a) Is the stream and its surrounding area a good place for:		b) Do you or your family actually do any of these activities there?
Fishing	____	____
Wading	____	____
Picnicking	____	____
Sitting	____	____
Playing ball, games	____	____
Walking	____	____
Bird watching	____	____
Ice skating	____	____
Other ________________	____	____

(If none of the categories above are checked:) Do you visit the stream at all?

yes ____

no ____

Why? ____________________

____

____

4.a) Approximately how many feet from the stream is your house located?

______ feet

b) How is it situated with respect to the stream?

It is right next to the stream ____

It has a view of the stream ____

It lies within a five minute walk from the stream ____

It is farther than five minutes away from the stream ____

5. Would you rather live nearer to the stream or farther away from it? (In a house like your present one, disregarding inconveniences due to moving, etc.) Check one.

I would rather stay where I am now, the house is very nicely located with respect to the stream ____

I would rather live in a house right next to the stream ____

I would rather live in a house with a view of the stream ____

I would rather live within a five minute walk from the stream ____

I would rather live even farther away: the farther the better ____

It doesn't make any difference to me. The stream is not important to me one way or the other ____

Comments ____

____

6. If you own your home, do you think the value of the house is affected by the presence of the creek?

Value not affected by creek ____

$____more because of creek

$____less because of creek

Present value of your house $ ____

If you rent, by how much do you think the presence of the creek increases or decreases your monthly rent from what it would be otherwise?

Rent not affected by creek ____

$____more because of creek

$____less because of creek

Present rent: house $ ____

apartment $ ____

7. In general, do you think that houses with the stream bordering their back yards are worth more or less because of their closeness to the stream?

much more____ a little more ____ same____ a little less ____ much less____

8. Judging from your own observations, how polluted do you think the stream is?

Very polluted____	somewhat polluted____	a little polluted____	not at all polluted ____	don't know____

If polluted:

What are the most noticeable signs of pollution in this particular stream?

____

____

9. If you had information that the stream was polluted and could identify the major polluters, what would you do?

I would not do anything, since I think adequate action would be taken by appropriate agencies ____

I would not do anything since my actions would have little effect ____

I would do one or more of the following:

write letters to government officials ____

organize neighbors for legal action ____

write letters to major polluters ____

organize or take part in clean-ups ____

join organizations of my neighbors ____

picket major polluters ____

10. Would you be willing to pay an increase in your real estate tax to help clean up the stream or do you think that is really not necessary?

I am willing to pay more ____ How much more? $______

I would not be willing to pay more ____

Why?____

____

11. How would you rate yourself with respect to environmental problems and pollution?

very concerned____	somewhat concerned____	a little concerned____	not at all concerned____	don't know____

12. How long have you lived in your present home or in the immediate neighborhood?

_______years

Household Information:

Number of adults in household ______

Number of children in household ______boys, ages______________________

______girls, ages______________________

Adults:	yourself	2	3	4
Sex	M___ F___	M___ F___	M___ F___	M___ F___
Age	___years	___years	___years	___years
Marital Status				
Single	___	___	___	___
Married	___	___	___	___
Divorced	___	___	___	___
Widowed	___	___	___	___
Education				
High School	___years	___years	___years	___years
College	___years	___years	___years	___years
Higher	___years	___years	___years	___years
Occupation	________	________	________	________

Yearly Income (Before Taxes) If family, put down joint income of husband and wife, plus contributions of other adults, in first column. If not a family, give individual incomes of each adult household member in appropriate column.

Under $ 5,000	___	___	___	___
$ 5 - 10,000	___	___	___	___
$10 - 15,000	___	___	___	___
$15 - 20,000	___	___	___	___
$20 - 25,000	___	___	___	___
Over $25,000	___	___	___	___

Where did the adult members of your household spend most of their lives before they were 18 years of age?

in rural area	___	___	___	___
in suburban area	___	___	___	___
in urban area	___	___	___	___

Please mail completed questionnaire in prepaid envelope to the:
Regional Science Research Institute
GPO Box 8776
Philadelphia, Pennsylvania 19101

VIII. CONCLUSIONS

EVALUATION OF EFFECTS

The research carried out under this project has made it possible to make a rough evaluation of the effects summarized in Table 1 in the Introduction to this report. Such a rough evaluation is given in Table 46, whose form resembles that of Table 1. The effects in question refer to a land use plan such as the Brandywine Plan which would involve some limitation on overall development but would pertain primarily to restricting development in critical areas.

Several of the value-related effects listed in the table were not the subject of original research, namely "ecological" benefit, reduced flood damages, and reduced need for water treatment. A survey of the literature indicates that the benefits of the plan would be rather small for water treatment. In the case of flood damages, the reduction in losses due to lower peak flows should be moderate,in line with the moderate reduction in peak flows resulting from the plan. Flood damages might also be moderately or even strongly reduced by the plan in that development is prevented from encroaching on areas subject to flooding. Quantitative estimates of the ecological benefits are not possible but it appears clear that greater ecological benefits would result from better water quality and more open space than from more stable streamflow.

One of the physical effects listed in Table 46 was not the subject of original research in this study, namely the effect of urbanization in reducing low or base flow of the stream. It has been hypothesized that the rendering of land impervious by preventing infiltration of water into the soil will cause a decrease in base flow. However, there is some evidence that in typical urbanized areas this effect is compensated for by importation of water into the watershed. At any rate, the effect appears to be small.

Our studies of stream channel enlargement, which is relevant to peak flow characteristics (i.e., average annual flood),

Table 46

ROUGH EVALUATION OF EFFECTS OF A PLAN FOR STREAM VALLEY PRESERVATION

Physical Changes		Potential Magnitude of Value-Related Effects				
Type of Change	Probable Magnitude of Change	More Active Use	More Visual Enjoyment	More Ecological Benefit	Reduced Flood Damages	Reduced Need for Water Treatment
More stable streamflow						
Higher base flow	small	small	small	small	---	small
Lower peak flows	moderate	small	small	small	moderate	small
Better water quality	moderate	moderate	moderate	large	---	small
More open space	large	large	large	large	moderate	---

indicates rather clearly that the overall density of development is considerably more important to peak flow increase than the distance of development from the stream. Therefore, the effect of a plan such as the Brandywine Plan would be only a moderate reduction in peak flows relative to the flows which would occur with normal development. Our studies of environmental preferences do not indicate that the reduction in peak flows would have more than a small effect on the value derived from active use and visual enjoyment.

Our research with regard to water quality indicates that water quality contaminants are generally positively related to amounts of various types of urban development. For development involving houses with on-site disposal of sewage the distance from the stream was found to be a significant factor. These results would indicate that the effect of a Brandywine-type plan would be of moderate size. With regard to the value-related effects of water quality, our studies of environmental preference have found that persons seeing a stream for the first time are able to perceive water quality reasonably well but do not appear to give this factor much weight in their stated preference for stream sites. However, for persons living near stream sites significant correlations have been found between water quality and the amount of active use. From this information we have concluded that better water quality, as would result from the plan, would have a moderate effect on active use and visual enjoyment, for the range of improvement in water quality which might be expected to result from the plan.

With regard to open space, our studies have indicated that although somewhat less development tends to occur in stream valleys than elsewhere, even in the absence of strong planning controls, the restriction of development near streams, as envisioned in the Brandywine Plan, would result in there being much more open space than would be preserved with typical urbanization. It is felt that this large open space effect would have correspondingly large effects on active use and enjoyment.

In general, the overall conclusion from Table 46 is that the value-related effects associated with open space may be as great or greater than those associated with streamflow and water quality characteristics.

The value-related effects listed in Table 46 may all be reflected in the value of land located near protected areas. The existence of such effects has been demonstrated by our study of the area surrounding Pennypack Park in Philadelphia. The reflection of values in real estate is important since it provides a way to measure value-related effects which themselves can be identified only through elaborate attitude surveys. Whether or not the real estate values generated by a land use protection plan will exceed the land value lost because of restriction of development must be established in future research.

IMPLICATIONS FOR PROJECT PLANNING

The benefits listed in Table 46 should be considered potential benefits, many of which will be fully realized only if people who value the environment move into the planned area.

Our research results indicate that the appreciation of and concern for the natural environment of the average person are rather mild. Although most persons seem to be able to identify water pollution reasonably well, environmental quality does not seem to make a drastic difference to their appreciation of an area or the use which they are likely to make of it. Furthermore, there are indications that considerations involving the natural environment may not be as important as other considerations in choosing a residential location. It is possible that most people do not systematically enter environmental considerations in their calculations of residential value, even though these considerations may actually be important to them. It is especially likely that the possibility of future deterioration, and the consequent benefits of preservation are not given adequate weight. The implications of environmental change do not appear to be considered as explicitly as, for example, the implications of change in the "type of neighbors."

A conclusion indicated by our research would be that a typical cross-section of people would not be willing to pay a large price for the type of environment guaranteed by a Brandywine-type plan. There is a good possibility, however, that subgroups exist within the population that would pay such a cost. This means, first, that for initial projects, areas must be selected carefully to assure the support of existing residents.

Second, there may have to be a merchandizing process by which members of that sub-group of the population who especially value environmental considerations are made aware of the advantages of the plan and are attracted to the area. Market analyses, which focus on the specific sub-group rather than on a general cross-section as in most of our research, will be needed. This is not unlike the approach to marketing employed by most large-scale house builders.

This discussion has referred to demonstration projects which involve only a small proportion of a metropolitan area. The goal is that eventually such plans might be enacted on a much larger scale. It should be noted that large-scale programs differ from small-scale single projects in a significant respect. For a small-scale project such as the Brandywine Plan the restriction of development in critical areas of the watershed does not appreciably affect the overall supply of land in the metropolitan housing market. Therefore, there is no automatic tendency for land values to rise in the unrestricted portions of the watershed because of scarcity. Increases in land values must be due entirely to the environmental benefits of the plan. For a whole metropolitan area, however, the enaction of restrictions would cause an effective reduction in the overall supply of land (i.e., the amount of land at various distances from the metropolitan center). Therefore there would be an automatic tendency for land values to rise in unrestricted areas. This provides a virtual guarantee that property tax revenues can be increased to pay for recompensing the owners of restricted land. Therefore, environmental planning is, at least in theory, somewhat easier on a large scale.

Due to the above considerations, small-scale demonstration projects may need proportionately more public funds than large-scale proposals. The fact that small-scale projects may have to be rather heavily subsidized does not mean that larger-scale programs will have to be.

A number of small-scale projects should be begun in the near future. These would be valuable in demonstrating the benefits of environmental preservation and thereby increasing public awareness of the possibilities of better patterns of urban development and the methods of achieving it.

ISSUES ARISING FROM THIS STUDY

Our results suggest two major areas in which future plans and future research might be different in emphasis from the Brandywine Plan. The first relates to the physical effects of urbanization on stream conditions. The research summarized here has focused on two factors: the density of development and the distance of development from the stream. Density has been found to be critically important, but to a certain extent must be taken as a given over a watershed. Distance of development from the stream was found to be considerably less important. Therefore, although much more should be learned about the effects of urban patterns on streamflow and water quality, future efforts might well, then, pay somewhat more attention to the design of development than to density and location. For example, in the case of peak streamflow increase due to impervious development, little is known concerning the amount of improvement which might be brought about by design of areas such as parking lots so as to retard the flow of rainwater in its flow to the stream. Also, storm sewers on local streets might be purposely underdesigned to provide temporary storage of storm water. It is suspected that the improvement that might be brought about by such methods would be greater than that from seeking an optimal location pattern for development.

The second possible change in emphasis relates to the value of open space to the residents of an area. The research reported here has indicated that most persons place only a moderate value on streams and stream quality. Therefore, the most important aspect of a plan such as the Brandywine might be the preservation of open space, per se. Although there is a natural association between the preservation of open space and the preservation of stream quality, it may be advantageous in formulating future plans to attempt explicitly to maximize the availability of open space itself to residents of the area. This may, of course, involve protection of open space in areas other than stream valleys.

Considerable further research needs to be done regarding the value of open space to the residents of an area, with the object of determining what size, arrangement, and topographic characteristics of open-space parcels provide the greatest benefit. It is important to continue to consider the preservation of water quality as a goal in open space planning. The choice of land to be preserved should represent some mix of the two strategies of maximizing open space value and minimizing stream quality deterioration.

BIBLIOGRAPHY

Alonso, W. 1964. *Location and Land Use: Toward a General Theory of Land Rent*. Cambridge, Mass.: Harvard University Press.

American Public Works Association. 1969. *Water Pollution Aspects of Urban Runoff*. FWQA Research Report No. WP-20-15, Washington: Department of the Interior, January.

Anderson, D.G. 1968. "Effects of Urban Development on Floods in Northern Virginia," U.S. Geological Open-File Report.

Babbitt and Doland. 1955. *Water Supply Engineering*. New York: McGraw-Hill Company.

Bringham, E.F. 1965. "The Determinants of Residential Land Values," *Land Economics*, Vol. 31, pp. 325-334.

Brown, R.M., N.J. McClelland, R.A. Deininger and R.G. Tozer. 1970. "A Water Quality Index-- Do We Dare?" presented at National Symposium on Data and Instrumentation for Water Quality Management, University of Wisconsin, Madision, Wisconsin, July 20-23.

Buckman, H.O. and N.C. Brady. 1960. *The Nature and Properties of Soils*. New York: Macmillan Company, 6th Edition.

Bucks County Division of Natural Resources. 1969. *Water Quality Monitoring Program*. Year End Report.

Bureau of the Budget. 1967. *Standard Industrial Classification Manual.* Washington: U.S. Government Printing Office.

Carrothers, G.A.P. 1956. "An Historical Review of the Gravity and Potential Concepts of Human Interaction," Journal of the American Institute of Planners, Vol. 22, pp. 94-102.

Carter, R.W. 1961. "Magnitude and Frequency of Floods in Suburban Areas," Short Papers in the Geologic and Hydrologic Sciences: U.S. Geological Professional Paper 424-B, p. B9-B11.

Chapin, F.S. and S.F. Weiss. 1962. Factors Influencing Land Development. Chapel Hill, North Carolina: Institute for Research in Social Science, University of North Carolina, August.

Clonts, H.A., Jr. 1970. "Influence of Urbanization on Land Values at the Urban Periphery," Land Economics, Vol. 46, pp. 489-497.

Coughlin, R.E. and K.A. Goldstein. 1970. "The Extent of Agreement among Observers on Environmental Attractiveness," RSRI Discussion Paper Series: No. 37, February.

_____________ and J. Fritz. 1971. "Land Values and Environmental Characteristics in the Rural-Urban Fringe," RSRI Discussion Paper Series: No. 45, May.

_____________ S. Sheldon, and T.R. Hammer. 1971. "The Intensity of Development Along Small and Medium-Sized Streams in Suburban Philadelphia," RSRI Discussion Paper Series: No. 50, September.

_____________ F. Taieb, and B.H. Stevens. 1972. Urban Analysis of Branch Library System Planning. Westport, Conn.: Greenwood Publishing Corporation.

_____________ T.R. Hammer, T.G. Dickert and S. Sheldon. 1972. "Perception and Use of Streams in Suburban Areas: Effect of Distance from Residence to Stream," RSRI Discussion Paper Series, forthcoming.

Craik, K.H. 1968. "Human Responsiveness to Landscape: An Environmental Psychological Perspective," *Student Publication of the School of Design*, North Carolina State University, Raleigh, N.C.

__________. 1969. *Forest Landscape Perception*. Final Report, Institute of Personality Assessment and Research Bulletin, University of California, Berkeley.

Czamanski, S. 1966. "Effects of Public Investment on Urban Land Values," *Journal of the American Institute of Planners*, Vol. 32, pp. 204-217.

David, E.L. 1968. "Lakeshore Property Values: A Guide to Public Investment in Recreation," *Water Resources Research*, Vol. 4, pp. 697-707.

Donnelly, T.G., F.S. Chapin, and S.F. Weiss. 1964. *A Probabilistic Model for Residential Growth*. Chapel Hill, North Carolina: Institute for Research in Social Science, University of North Carolina, May.

Downing, P.B. 1969. "Estimating Residential Land Value by Multivariate Analysis," paper presented at Conference of the Committee on Taxation, Resources, and Economic Development, University of Wisconsin-Milwaukee, June.

Eckenfelder, W.W. (Ed.). 1969. *Manual of Treatment Processes*. Water Resource Management Series, Vol. 1, Environmental Science Services Corporation.

Economic Systems Corporation. 1970. *Storm Water Pollution for Urban Land Activity*, a report to the Federal Water Quality Commission, Washington: U.S. Government Printing Office, July.

Gloyna, E.F. and W.W. Eckenfelder (Eds.). 1968. *Advances in Water Quality Improvement*. Water Resources Symposium No. 1, University of Texas Press.

Grava, S. 1969. *Urban Planning Aspects of Water Pollution Control*. New York: Columbia University Press.

Haig, R.M. 1962. "Toward an Understanding of the Metropolis," *Quarterly Journal of Economics*, Vol. 40, pp. 179-208.

Hammer, T.R. 1970. "Criteria for Measurement of Stream Channels as an Indicator of Peak Flow History," *RSRI Discussion Paper Series: No. 36*, February.

__________. 1971. "The Effect of Urbanization on Stream Channel Enlargement," unpublished Ph.D. dissertation, University of Pennsylvania, August.

__________, E.T. Horn, IV, and R.E. Coughlin. 1971. "The Effect of a Large Urban Park on Real Estate Value," *RSRI Discussion Paper Series: No. 51*, September.

Hawkins, R.W. 1969. "The Effect of Changes of Streamflow Regimen on Reservoir Yield," *Water Resources Research*, Vol. 5, pp. 1115-1119.

Hem, J.D. 1959. *Study and Interpretation of the Chemical Characteristics of Natural Water*. Geological Survey Water Supply Paper 1473. Washington: U.S. Government Printing Office.

Institute for Environmental Studies, Regional Science Research Institute, and U.S. Geological Survey. 1968. *The Plan and Program for the Brandywine.* Philadelphia: Institute for Environmental Studies, University of Pennsylvania.

Isard, W. and E. Romanoff. 1967. "Water Utilization Input-Output Coefficients," *Technical Paper No. 5*. Cambridge, Mass.: Regional Science Research Institute, August.

Jacobs, P. and D. Way. 1968. *Visual Analysis of Landscape Development*. Harvard University, Graduate School of Design, Department of Landscape Architecture.

Kawashima, T., T.R. Hammer, and R.E. Coughlin. 1970. "Preliminary Analysis of the Effects of Urbanization on Water Quality," RSRI Working Paper.

Keene, J.C. and A.L. Strong. 1970. "The Brandywine Plan," Journal of the American Institute of Planners, Vol. 36, pp. 50-58.

Klein, L. 1959. River Pollution 1: Chemical Analysis. New York: Academic Press, Inc.

Kneese, A.V. and B.T. Bower. 1968. Managing Water Quality: Economics, Technology, Institutions. Baltimore: Johns Hopkins Press.

Knetsch, J.L. 1964. "The Influence of Reservoir Projects on Land Values," Journal of Farm Economics, Vol. 46, pp. 520-538.

Knos, D.S. 1962. Distribution of Land Values in Topeka, Kansas. Lawrence, Kansas: Center for Research in Business, University of Kansas, May.

Lansing, J.B. and R.W. Marcus. 1969. "Evaluation of Neighborhood Quality," Journal of the American Institute of Planners, Vol. 35, pp. 195-199.

Leopold, L.B., M.G. Wolman, and J.P Miller. 1964. Fluvial Processes in Geomorphology.: San Francisco W.H. Freeman and Company.

________________. 1968. "Hydrology for Urban Land Planning," U.S. Geological Survery Circular 554, Washington.

________________. 1970. "Let's Sing 'Auld Lang Syne' for the Upper Brandywine," Natural History, June-July.

McGauhey, P.H. 1968. Engineering Management of Water Quality. New York: McGraw-Hill Company.

McKee, J.E. and H.W. Wolf. 1963. Water Quality Criteria. The Resources Agency of California, State Water Resources Control Board.

Menchik, M.D. 1971. "Residential Environmental Preferences and Choice: Some Results Relevant to Urban Form," RSRI Discussion Paper Series: No. 46, March.

Michelson, W. 1966. "An Empirical Analysis of Urban Environmental Preferences," *Journal of the American Institute of Planners*, Vol. 32, pp. 355-360.

Nebieker, J.H. 1969. The Technology of Pollution Abatement," *The Massachusetts Heritage*, Vol. VII, No. 3,

Park, R.E. 1925. "The Growth of the City," in Park, Burgess, and McKenzie, *The City*. Chicago: The University of Chicago Press.

Peterson, G.L. and E.S. Neumann. 1969. "Modeling and Predicting Human Response to the Visual Recreation Environment," *Journal of Leisure Research*, Vol. 1, pp. 219-237.

Rabinowitz, C.B. and R.E. Coughlin. 1970. "Analysis of Landscape Characteristics Relevant to Preferences," *RSRI Discussion Paper Series: No. 38*, March.

__________ and _________. 1971. "Some Experiments in Quantitative Measurement of Landscape Quality," *RSRI Discussion Paper Series: No. 43*, March.

Rogers, C.E. and Associates. 1968. *Nature's Challenge to Man, Guidelines for Conservation and Development of Open Space in the Lower Brandywine Valley*. The Brandywine Valley Association.

Rummel, R.J. 1967. "Understanding Factor Analysis," *Conflict Resolution*, Vol. XL, pp. 444-480.

Scherer, U. and R.E. Coughlin. 1971. "The Influence of Water Quality in the Evaluation of Stream Sites," RSRI Working Paper, October.

Seymour, D.R. 1966. "Analysis of the Effects of Zoning Change on Property Values in Two Pittsburgh Suburbs," unpublished Ph.D. dissertation, University of Pennsylvania.

Shafer, E.L., Jr., J.F. Hamilton, Jr. and E.A. Schmidt. 1969. "Natural Landscape Preferences: A Predictive Model," *Journal of Leisure Research*, Vol. 1, pp. 1-20.

Soil Conservation Service, U.S.D.A., in cooperation with Pennsylvania State University and Pennsylvania Department of Agriculture. 1963. *Soil Survey for Chester and Delaware Counties*, *Soil Survey for Bucks County*, and *Soil Survey for Montgomery County*. Washington: U.S. Government Printing Office.

Soil Surveys for Montgomery County and Chester and Delaware Counties, Pennsylvania, prepared by the U.S. Department of Agriculture.

Stevens, B.H. and R.E. Coughlin. 1966. "An Outline for Economic Evaluation of Stream Valley Preservation," *RSRI Discussion Paper Series: No. 10*, July.

Thompson, P. 1969. "Brandywine Basin--Defeat of an Almost Perfect Plan," *Science*, Vol. 163, pp. 1180-82.

Ven Te Chow, (Ed.). 1964. *Handbook of Applied Hydrology--A Compendium of Water Resource Technology*. New York: McGraw-Hill, Inc.

PUBLICATIONS PRODUCED IN WHOLE IN MAJOR PART UNDER THIS GRANT

Coughlin, Robert E. and Karen A. Goldstein, THE EXTENT OF AGREEMENT AMONG OBSERVERS ON ENVIRONMENTAL ATTRACTIVENESS, RSRI Discussion Paper Series: No. 37, February 1970.

_____ and James Fritz, LAND VALUES AND ENVIRONMENTAL CHARACTERISTICS IN THE RURAL-URBAN FRINGE, RSRI Discussion Paper Series: No. 45, May 1971.

_____, Sallie Sheldon and Thomas R. Hammer, THE INTENSITY OF DEVELOPMENT ALONG SMALL AND MEDIUM SIZED STREAMS IN SUBURBAN PHILADELPHIA, RSRI Discussion Paper Series: No. 50, September 1971.

_____, Thomas R. Hammer, Thomas G. Dickert and Sallie Sheldon, PERCEPTION AND USE OF STREAMS IN SUBURBAN AREAS: EFFECTS OF WATER QUALITY AND OF DISTANCE FROM RESIDENCE TO STREAM, RSRI Discussion Paper Series: No. 53, March 1972.

Hammer, Thomas R.,THE EFFECT OF URBANIZATION ON STREAM CHANNEL ENLARGEMENT, Ph.D. doctoral dissertation, University of Pennsylvania, August 1971.

_____, Edward T. Horn, IV, and Robert E. Coughlin, THE EFFECT OF A LARGE URBAN PARK ON REAL ESTATE VALUE, RSRI Discussion Paper Series: No. 51, December 1971.

_____, CRITERIA FOR MEASUREMENT OF STREAM CHANNELS AS AN INDICATOR OF PEAK FLOW HISTORY, RSRI Discussion Paper Series: No. 36, February 1970.

_____, STREAM CHANNEL ENLARGEMENT DUE TO URBANIZATION, RSRI Discussion Paper Series: No. 55, May 1972.

_____, PROCEDURES FOR ESTIMATING THE HYDROLOGIC IMPACT OF URBANIZATION, RSRI Occasional Paper, September 1971.

_____, STREAM CHANNEL ENLARGEMENT DUE TO URBANIZATION, Water Resources Research, Vol. 8, No. 6, December 1972.

Kawashima, Tatsuhiko, Thomas R. Hammer and Rober E. Coughlin, PRELIMINARY ANALYSIS OF THE EFFECTS OF URBANIZATION ON WATER QUALITY, RSRI, 1970.

Menchik, Mark D., RESIDENTIAL ENVIRONMENTAL PREFERENCES AND CHOICE: SOME PRELIMINARY EMPIRICAL RESULTS RELEVANT TO URBAN FORM, RSRI Discussion Paper Series: No. 46, March 1971.

Rabinowitz, Carla B. and Robert E. Coughlin, ANALYSIS OF LANDSCAPE CHARACTERISTICS RELEVANT TO PREFERENCE, RSRI Discussion Paper Series: No. 38, March 1970.

_____ and Robert E. Coughlin, SOME EXPERIMENTS IN QUANTITATIVE MEASUREMENT OF LANDSCAPE QUALITY, RSRI Discussion Paper Series: No. 43, March 1971.

Scherer, Ursula and Robert E. Coughlin, THE INFLUENCE OF WATER QUALITY IN THE EVALUATION OF STREAM SITES, RSRI, 1971.

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